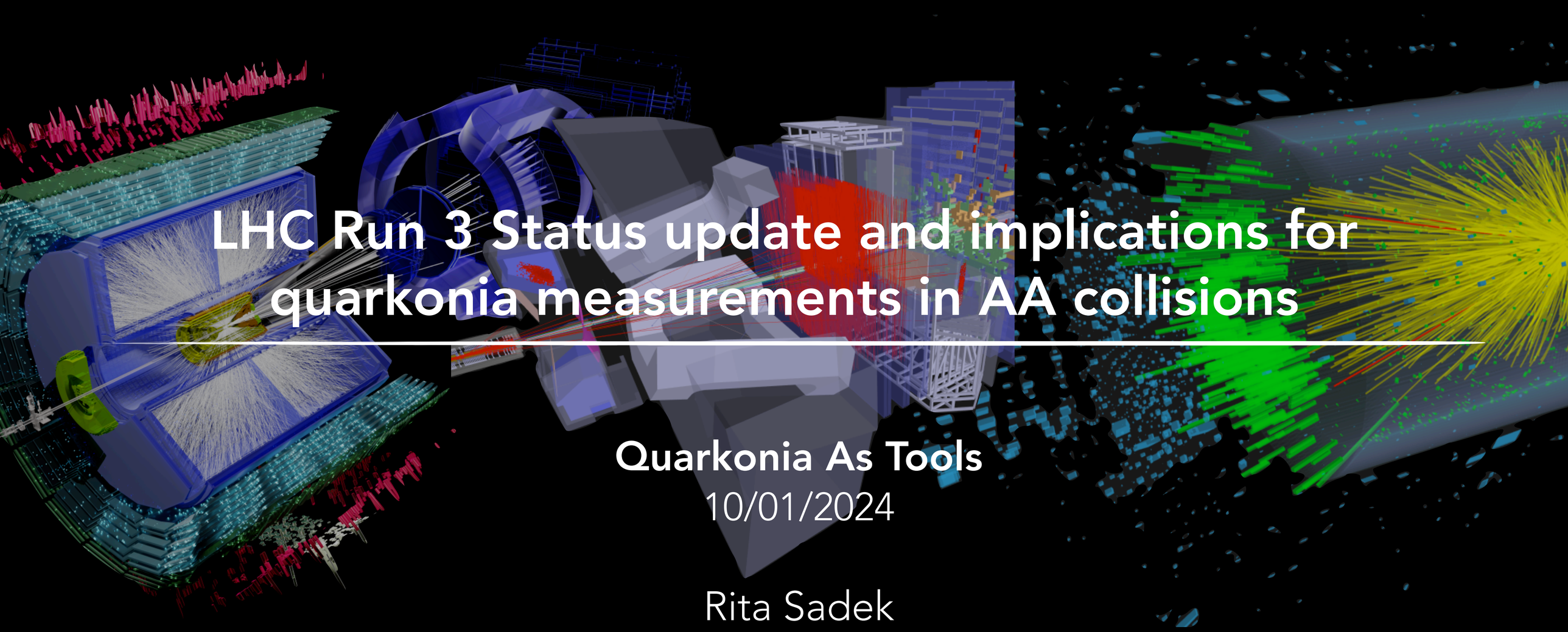
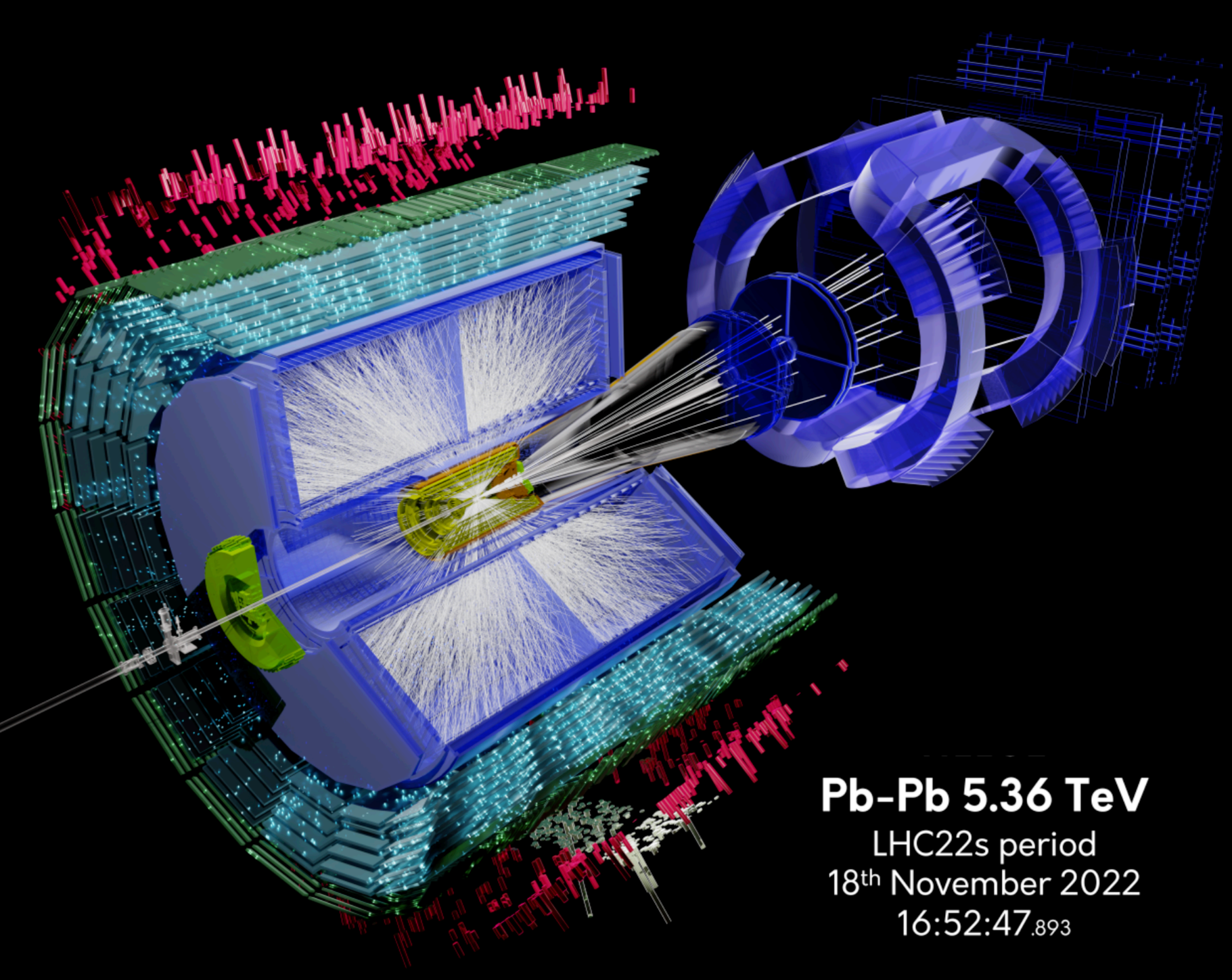


LHC Run 3 Status update and implications for quarkonia measurements in AA collisions

Quarkonia As Tools

10/01/2024

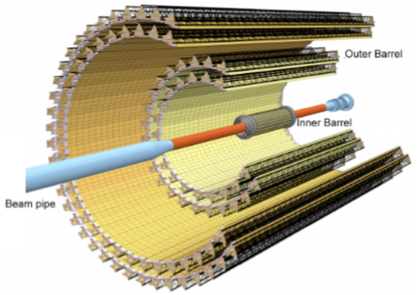
Rita Sadek



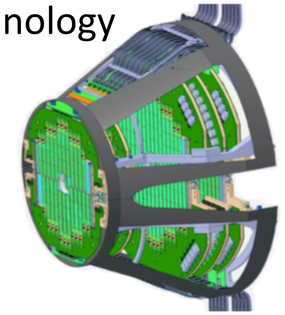
Run 3 overview:
ALICE

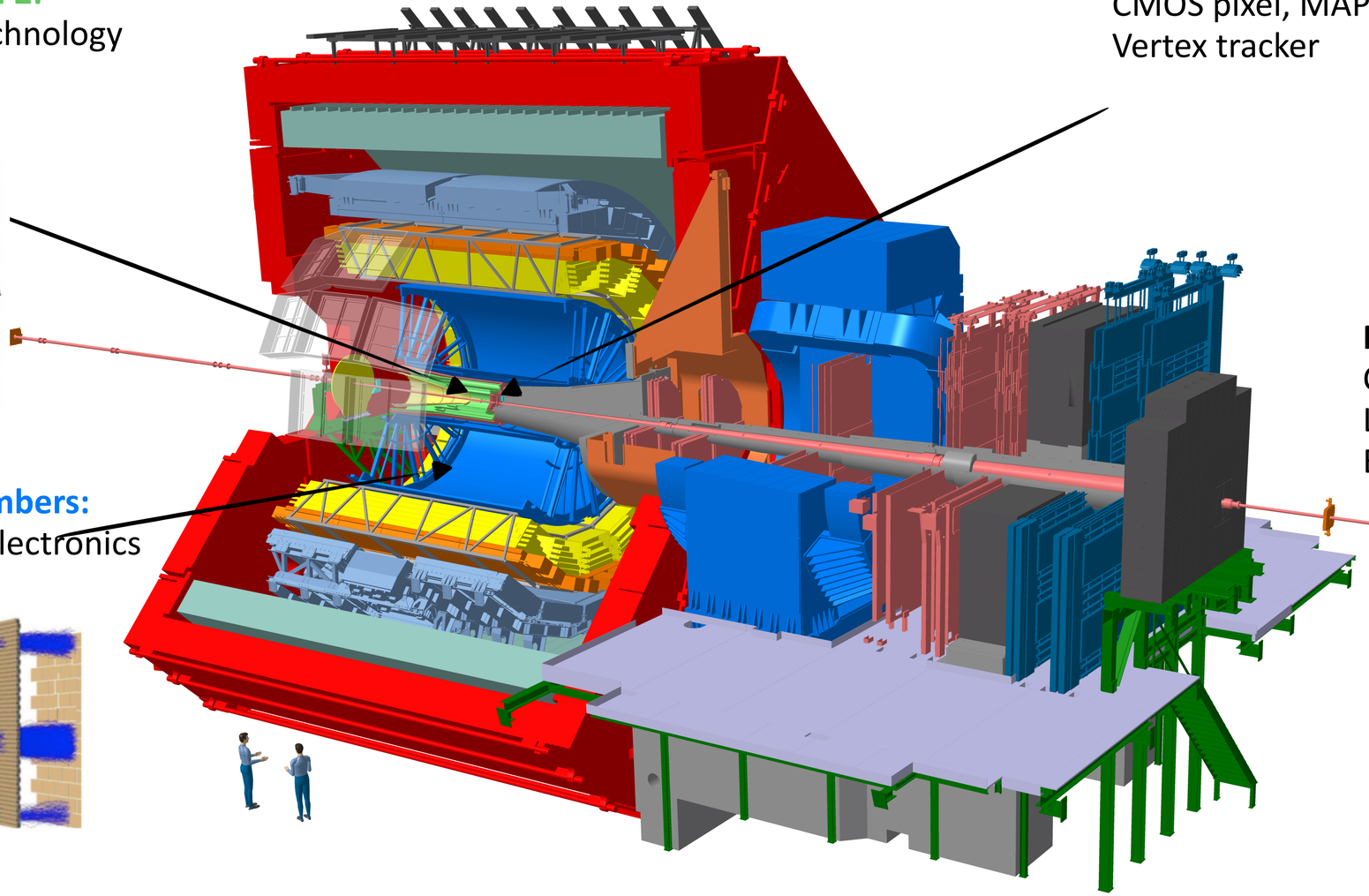
ALICE for Run 3

Inner Tracking System 2:
CMOS pixel, MAPS technology
Improved resolution
Faster readout

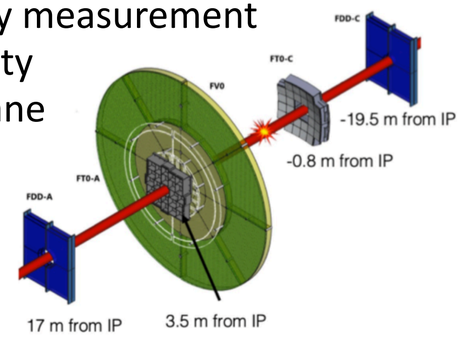


New Muon Forward Tracker:
CMOS pixel, MAPS technology
Vertex tracker

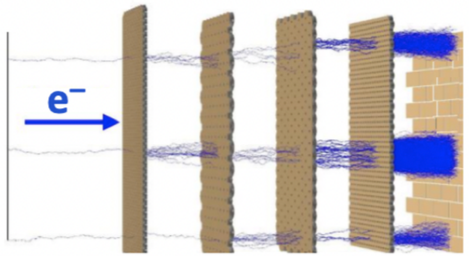




New Fast Interaction Trigger:
Centrality measurement
Luminosity
Event plane



New TPC Readout Chambers:
GEM technology, new electronics
Continuous readout



New computing system
(Online-Offline = O^2)

Readout upgrade for detectors

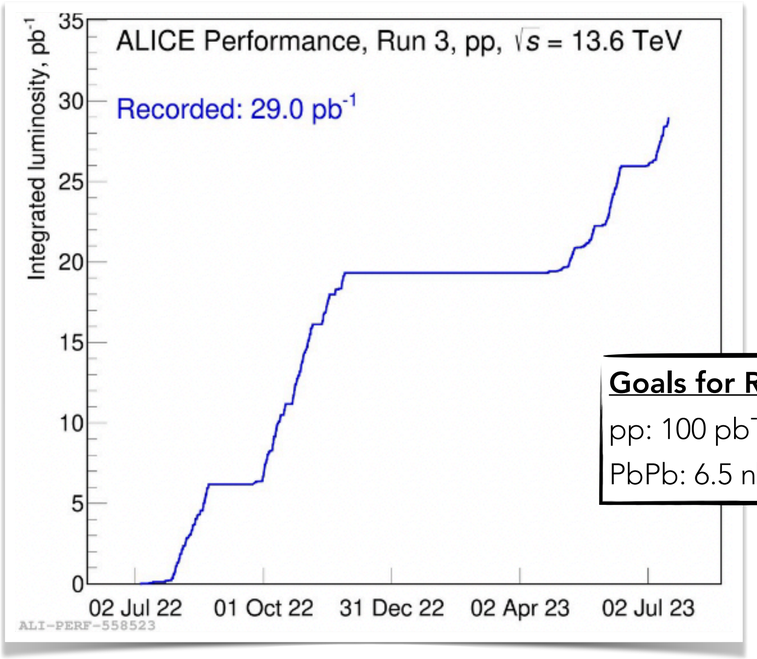
EMCAL, PHOS, TOF, TRD, MUON:
New readout electronics

Data processing

NEW **Record & reconstruct data in continuous readout**

- **Data taking at 500 kHz in pp & 50 kHz in Pb-Pb**
  - **Up to x50 increase of statistics**

Selection of high-multiplicity and rare events using software triggers with selection factor of around 10^{-4}



Goals for Run 3:
pp: 100 pb^{-1}
PbPb: 6.5 nb^{-1}

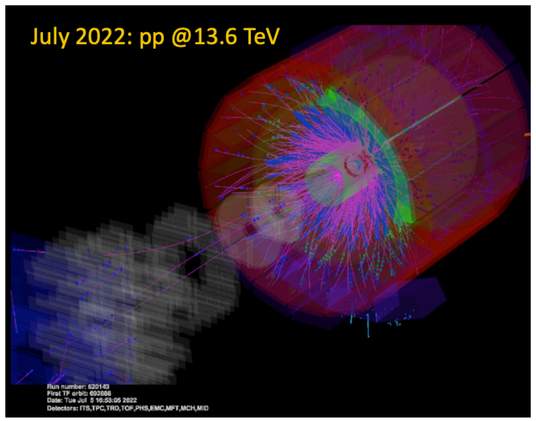
Few dates to resume Run 3:

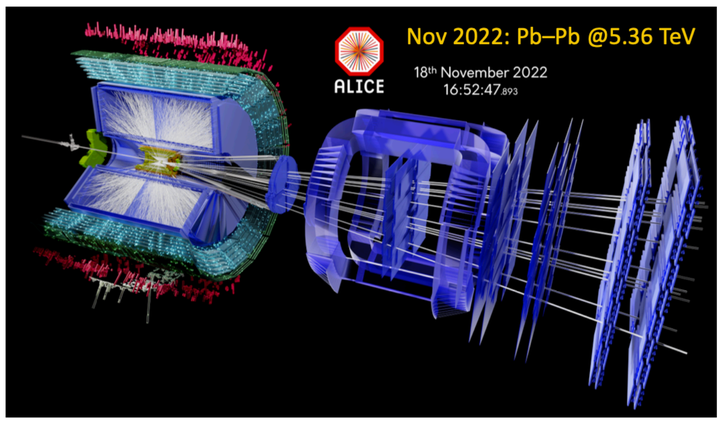
2022

- July 2022: **pp collisions at 10 kHz** at 13.6 TeV
  - pp physics data taking at ~500 kHz
  - Tests of pp at 1-4 MHz (3.5 MHz pp equivalent to Pb-Pb at 50 kHz)
- 13.8 pb^{-1} collected of 13.6 TeV pp at 500 kHz
- 17-18 November 2022: **Pilot beam Pb-Pb** at 5.36 TeV

2023

- April 6: first stable beam, pp at 0.9 TeV
- April 21: **first pp stable beam at 13.6 TeV**
  - physics data taking with gradual increase of interaction rate up to ~500 kHz, nominal data taking
- From 5th October: **25 days Pb-Pb** without beam background
  - Data taking around 47 kHz rate reached





Outlook from the different upgrades

Fast Interaction Trigger:

FT0:

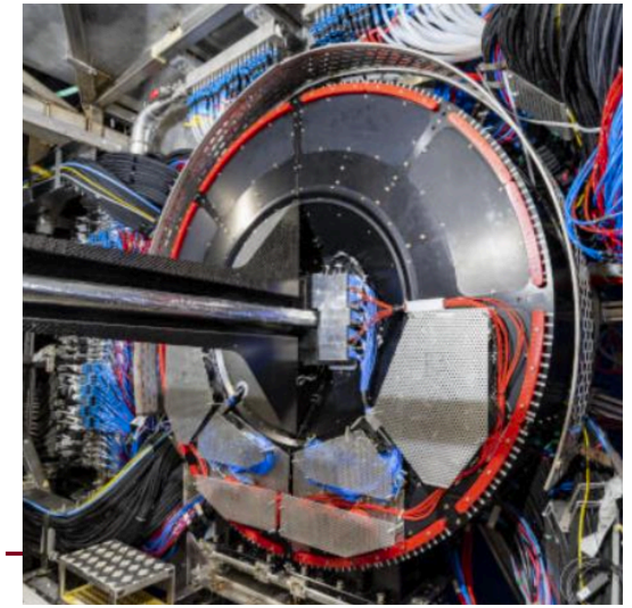
2 arrays of Cherenkov radiators
Optically coupled to micro-channel plate photomultiplier tubes
Main functions:
High precision in measuring collision time and vertex position
Luminosity and background monitoring

FV0:

5 large segmented scintillator rings
PMT readout system
Main functions:
Monitoring background & luminosity
Assessing multiplicity, centrality, and event plane

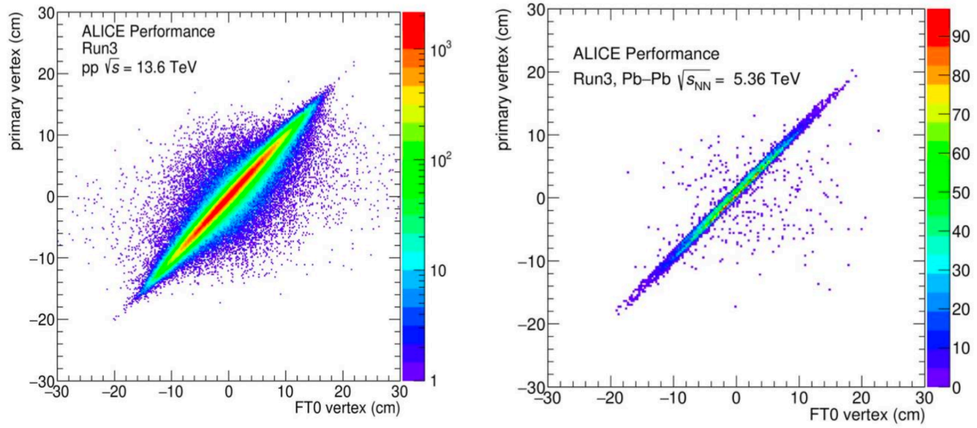
FDD (Forward Diffractive Detector):

2 double layer scintillator arrays
PMT readout system
Main functions:
Background monitoring
Forward vetoes for diffractive studies



Operations:

- Time resolution of 9 ps for Pb-Pb and 18 ps for pp collisions.
- Good correlations with primary vertex.



Outlook from the different upgrades

Inner Tracking System 2:

Provides tracking down to low pT, allows the determination of primary and secondary vertices.

Design

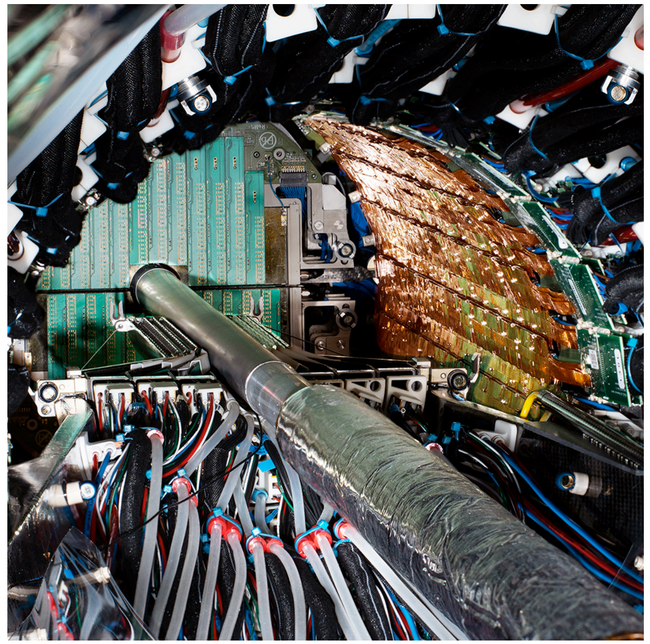
7 silicon layers located around the interaction point
Based on Monolithic Active Pixel Sensors technology
Equipped with ALPIDE chips, allowing continuous readout
Upgraded readout capabilities, handling high data-taking rate

Performance Requirements

Fake-hit rate: < 10^{-6}/event/pixel
Detection efficiency > 99%

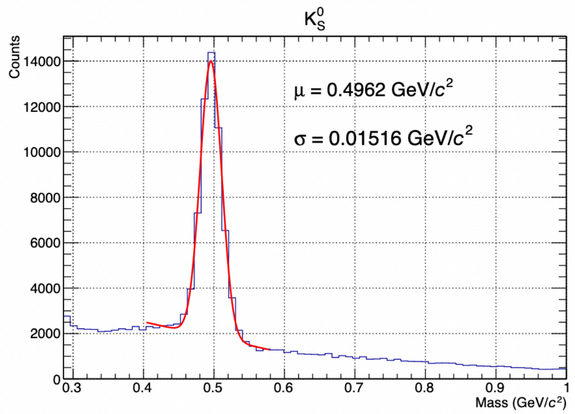
Improved resolution wrt ITS1

Impact parameter improved in the r - ϕ coordinate by a factor of around 3
The z-coordinate resolution improved by a factor of around 5 at pT = 0.5 GeV/c



Operations:

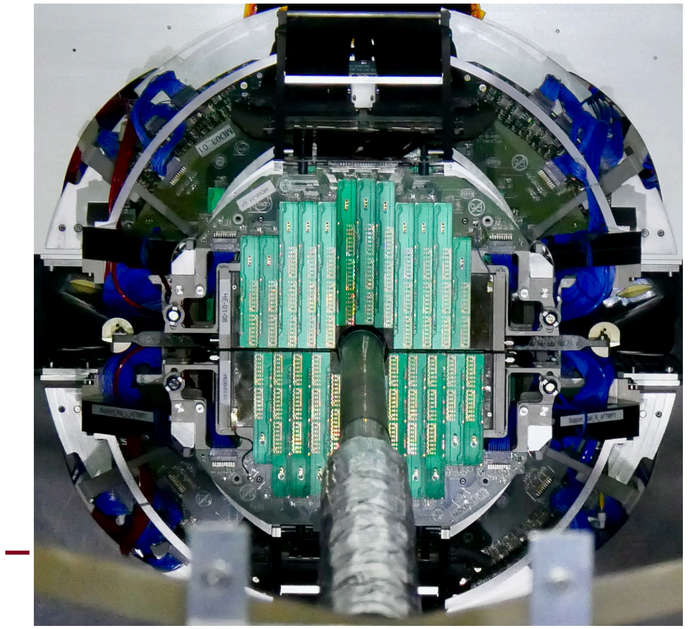
- 24k chips displaying good stability over time.
- Studies with ML ongoing to exploit cluster size to ID pions, kaons and protons down to pT < 0.1 GeV/c.



Outlook from the different upgrades

Muon Forward Tracker:

New *high resolution tracking detector in the forward rapidity region, installed around 40 cm after the interaction point, allowing precise determination of muon production vertices*



Design

936 silicon pixel sensors in 280 ladders
10 double-sided half disks
Based on Monolithic Active Pixel Sensors technology
Equipped with ALPIDE chips

Small spacial resolution (5 μm) for high tracking performance

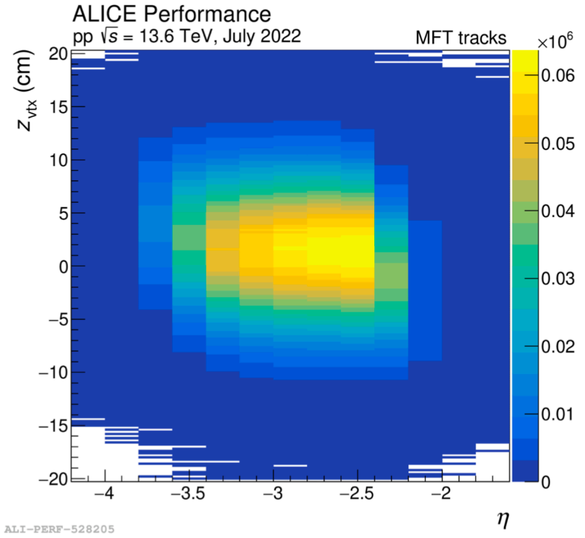
High readout capabilities for Run 3 data-taking rates

Radiant-tolerant material to withstand radioactive environment (400 kRad)

Low material budged preventing multiple scattering ($0.7\,\%\,X_0$)

Operations:

- Extremely low noise -> fake hit rate < 10^{-10}.
- Good tracking performance in pp and Pb-Pb collisions.



Outlook from the different upgrades

Time Projection Chamber:

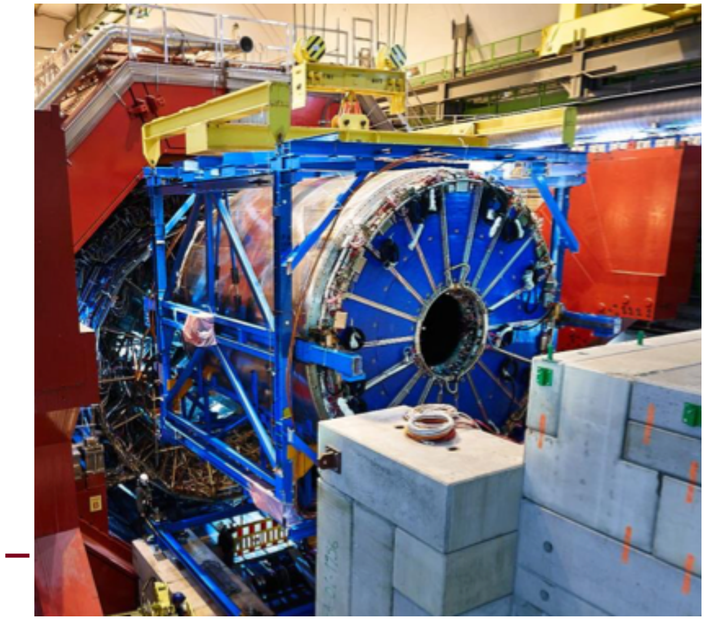
Main detector for tracking of charged particles and particle identification

Design

Transition from Multi-Wire Proportional Chamber to Gas Electron Multiplier technology, removing rate restrictions
36 inner and outer readout chambers

Operational Performance

Allows continuous readout, handles Pb-Pb collisions at 50 kHz

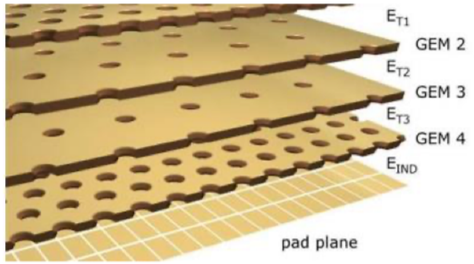


Utilizes a 4-GEM stack system

Avalanche creation in GEM hole

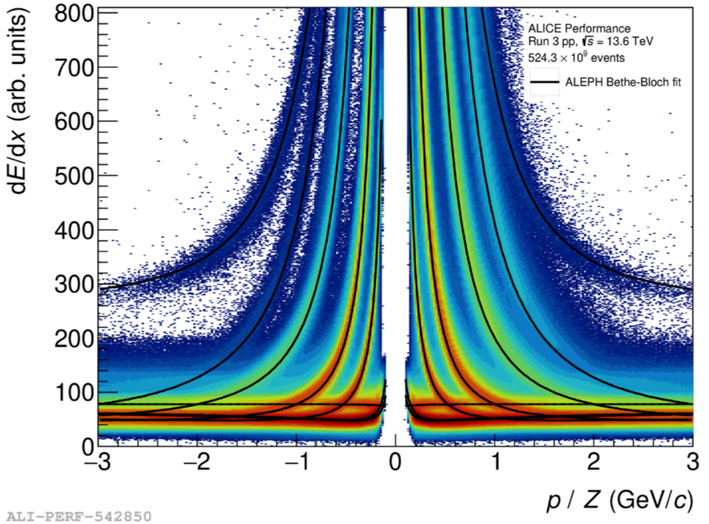
Specific configuration keeping ion backflow < 1%

Maintains similar dE/dx performance as MWPC



Operations:

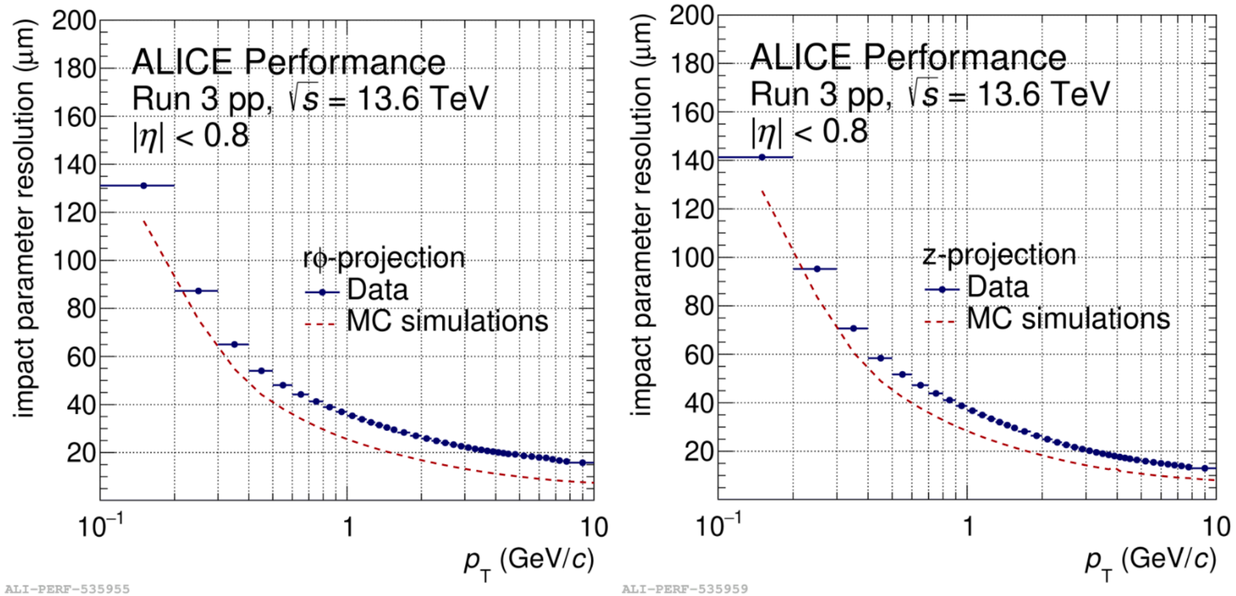
- Hyper parameter optimisation for initial Bethe-Bloch fit.
- Neural Network corrections for secondary effects + data-driven corrections.



First performances

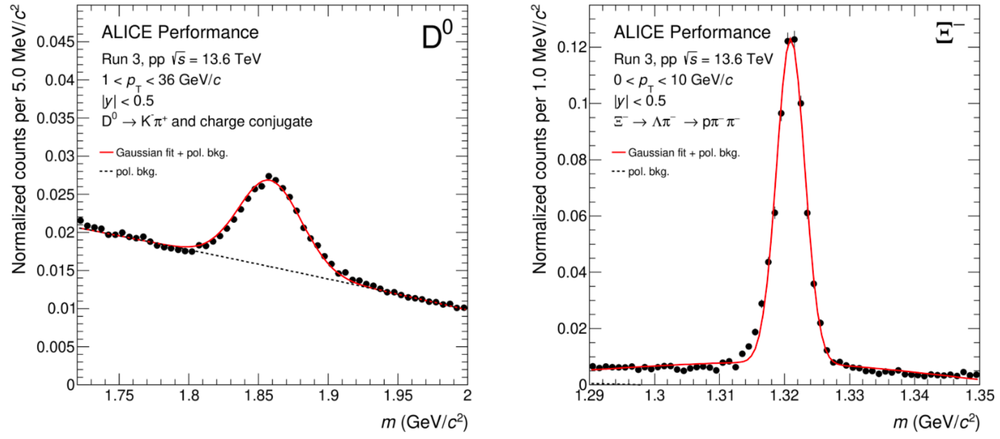
Impact parameter resolution:

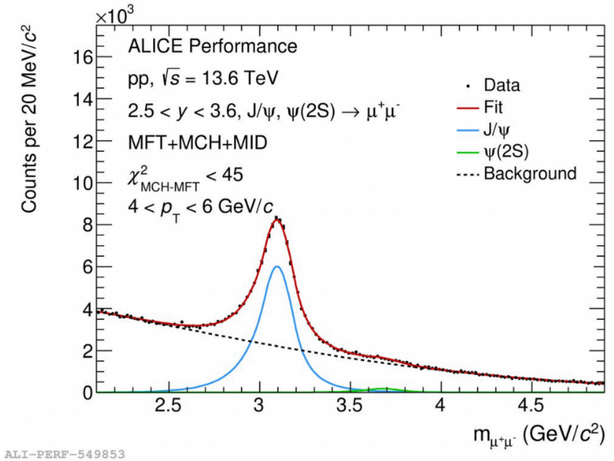
- Significantly improved pointing resolution with ITS2 agreement with simulations (difference attributed to residual misalignment)
- Improvement in $r\phi$ (x3) and z (x6) at low pT



First physics signals:

- Good reconstruction, improved signal/background ratio
- Significant improvements expected with new TPC calibrations

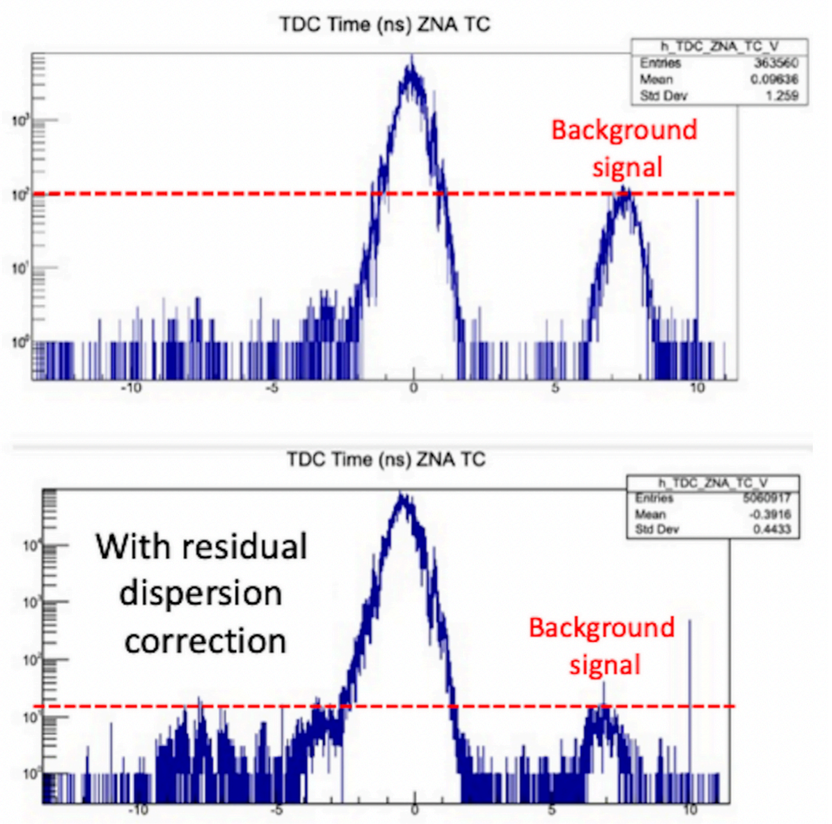




What about Pb-Pb ?

High beam background detected during initial operations:
ITS chips fully saturated, impacting acceptance.

Collimated particle flux parallel to beam pipe arising from losses on the TCT
Losses deviated to another collimator.

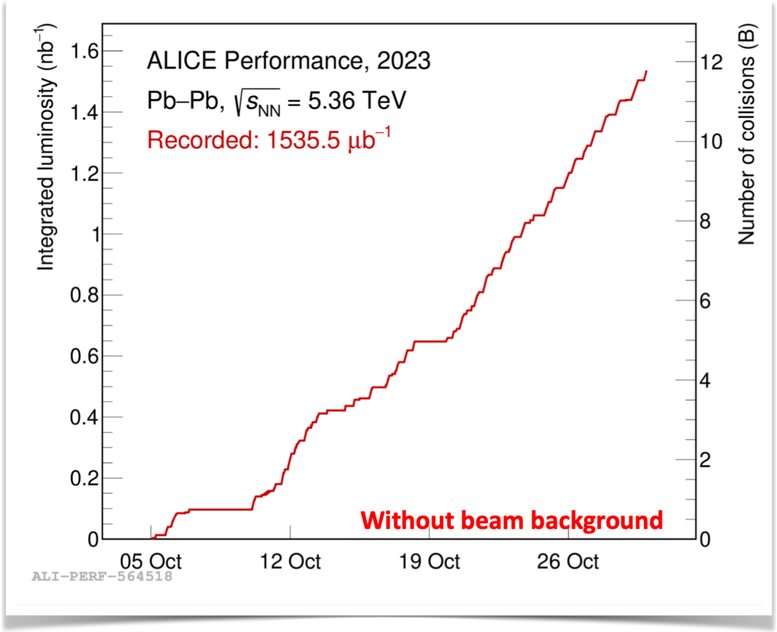


What about Pb-Pb ?

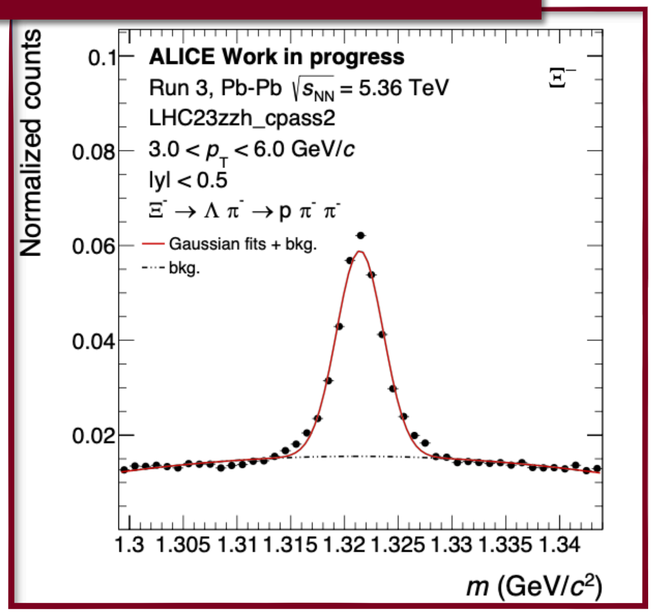
High beam background detected during initial operations:
ITS chips fully saturated, impacting acceptance.

Collimated particle flux parallel to beam pipe arising from losses on the TCT
Losses deviated to another collimator.

After 0.2 nb^{-1} delivered, operations back to normal



First physics signals in Pb-Pb



208 hours of HI data taking

Detectors hardware stable

<u>Collected sample much larger than RUN 1+2:</u>

Without background: 1.96 nb^{-1} (30% of total goal for Run 3)

Physics perspectives at mid-rapidity

Reduction in statistical uncertainties, lower pT ranges reach, better tracking efficiencies

Nuclear Modification Factor measurements:

Extended reach for D down to 0 GeV/c, statistical uncertainty expected to be improved from 10% to 0.3%

Ds measurable down to less than 2 GeV/c

J/ψ from B now measurable down to 1 GeV/c

NEW Capability to measure Λc/D^0 RAA down to 2 GeV/c

Elliptic flow measurements:

Extended reach for D down to 0 GeV/c

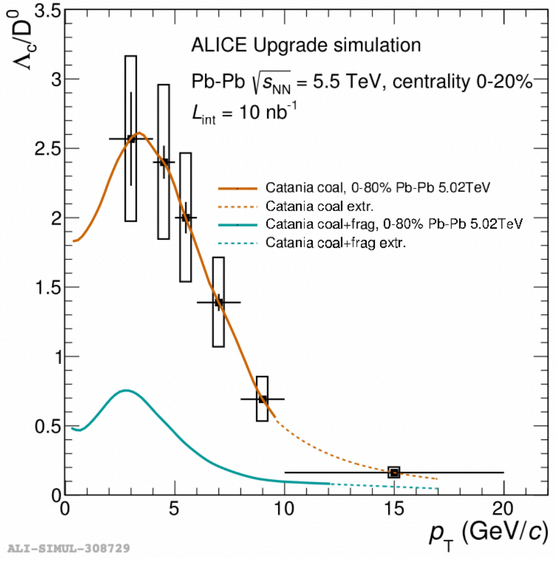
NEW Ds mesons measurable down to < 2 GeV/c

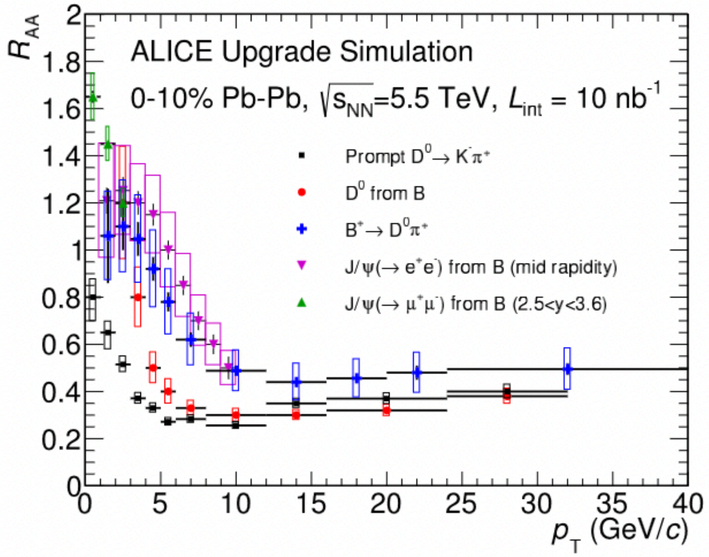
NEW J/ψ from B meson will be accessible down to 1 GeV/c

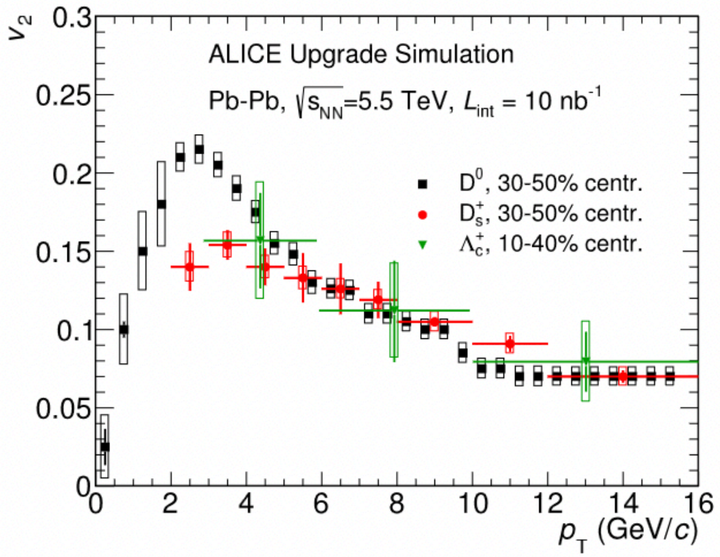
NEW Λc will be measurable down to 3 GeV/c

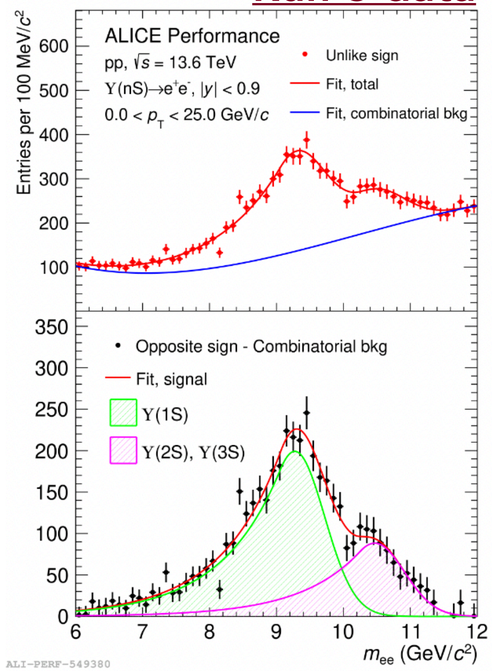
First Y(nS) measurements at mid-rapidity

Run 3 data







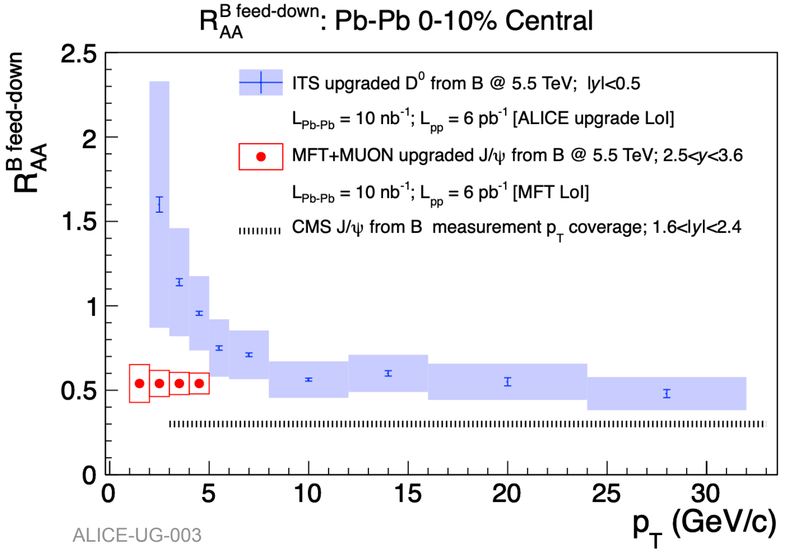


Physics perspectives at forward rapidity

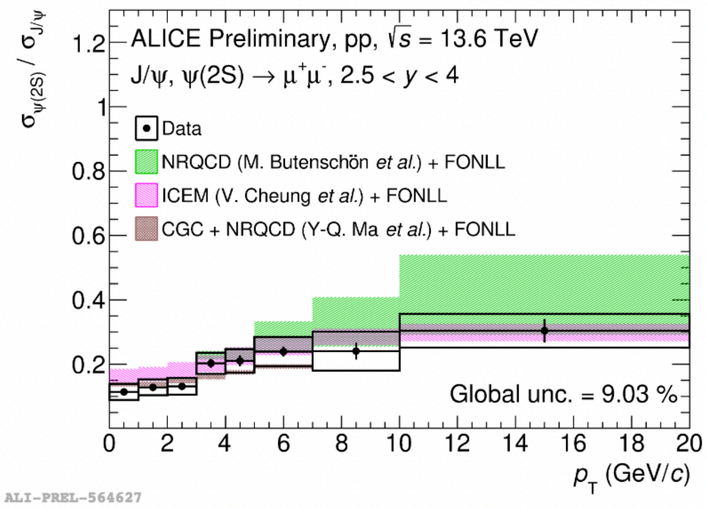
Heavy Flavors:
Less background expected → **low p_T reached**.
Separation between **charm and beauty** quarks.

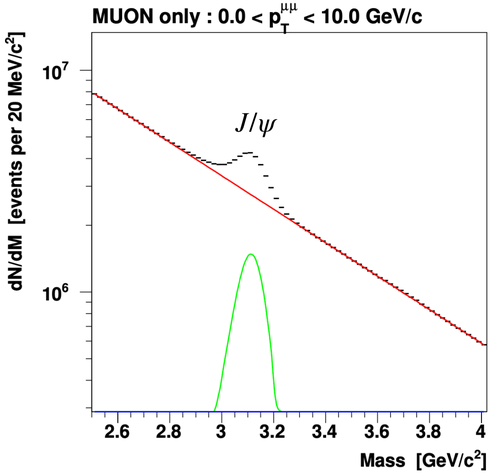
Charmonia:
Improvement of the S/B → **improved extraction of the ψ(2S)** signal.
Access to the **charmonia non-prompt fraction**.

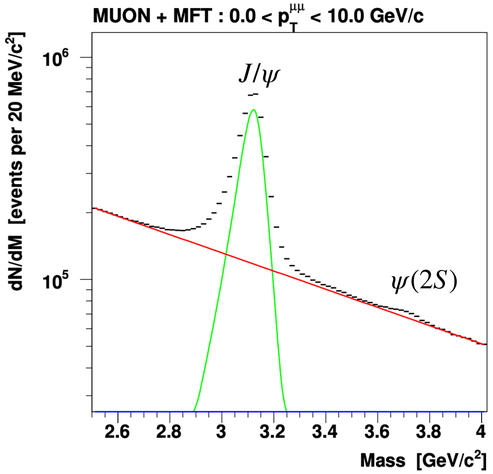
Low mass dimuons:
Better dimuon opening angle resolution → **better mass resolution**.

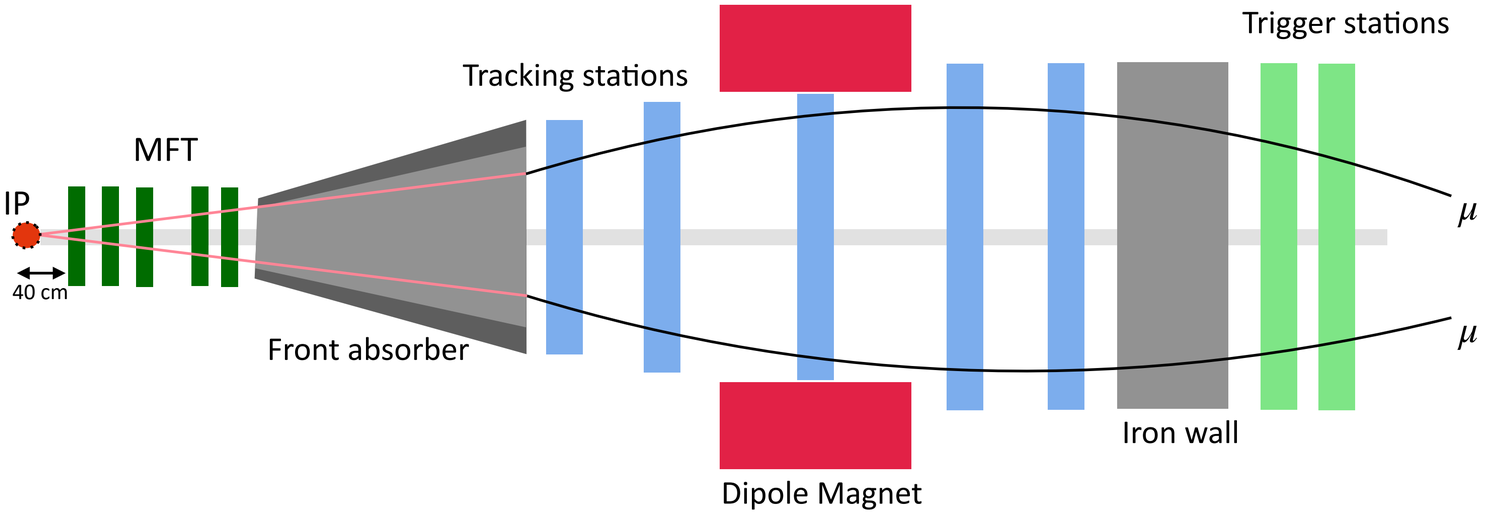


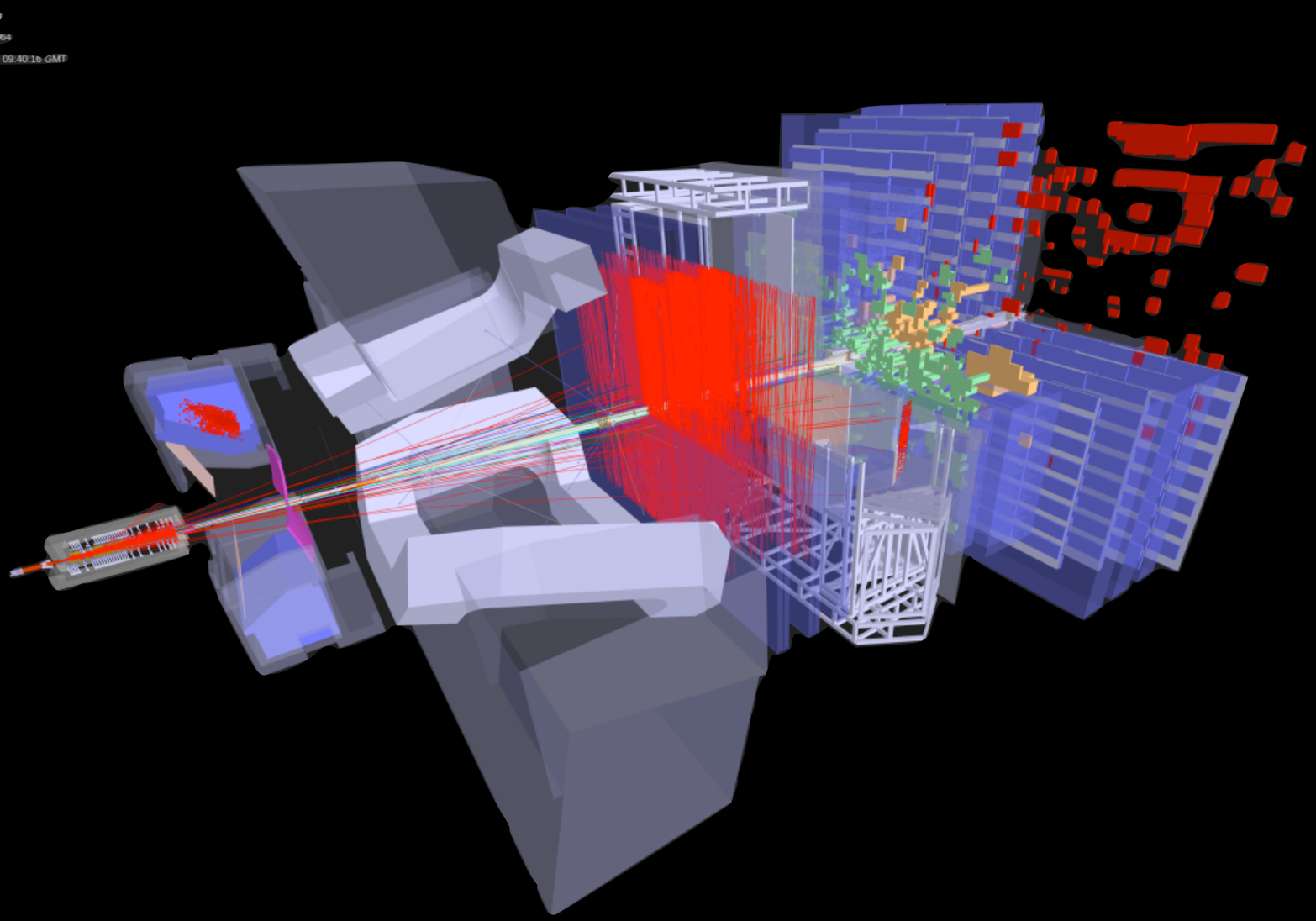
Run 3 data











Run 3 overview:
LHCb

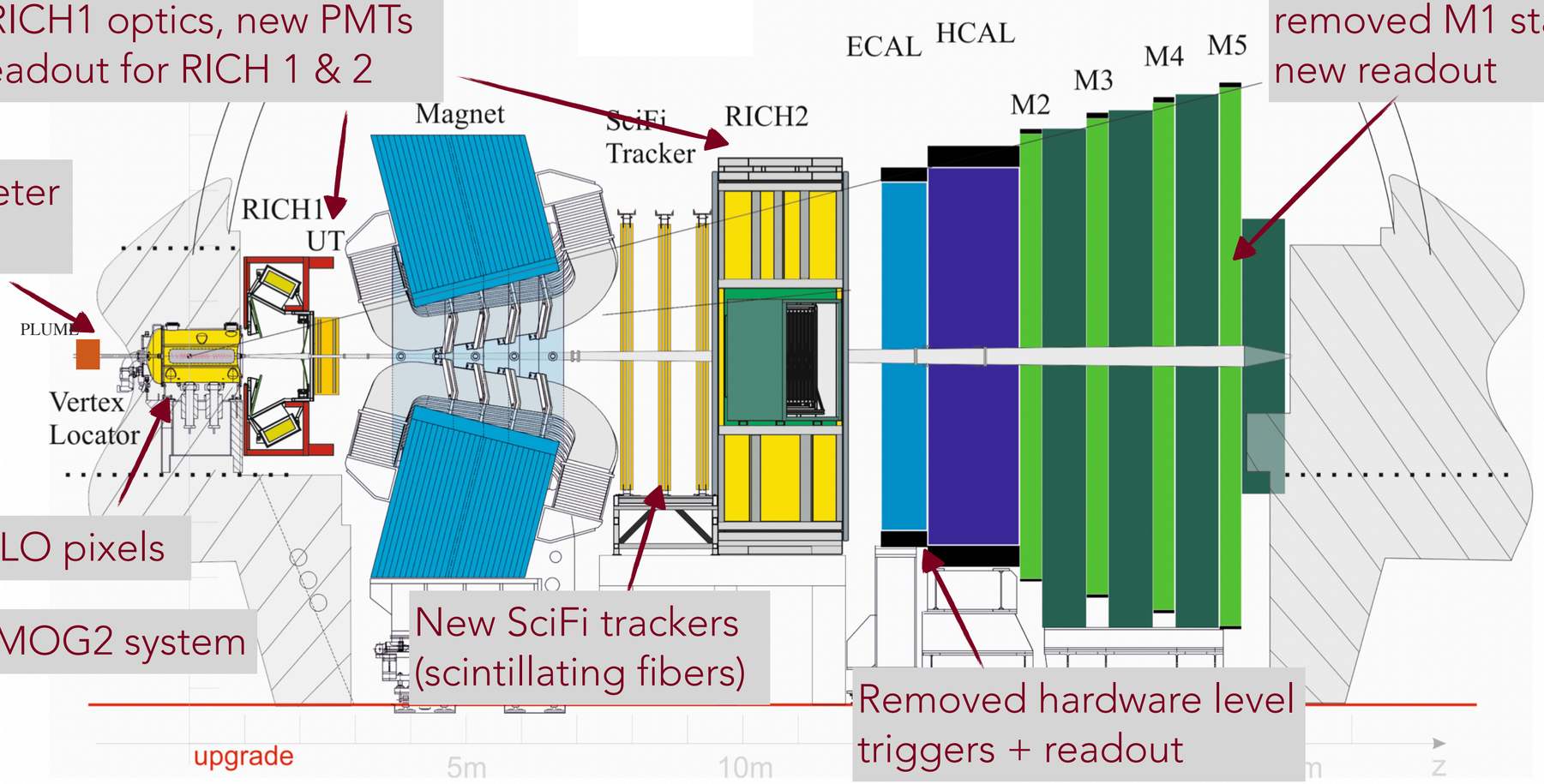
LHCb for Run 3

Single arm spectrometer in the forward range, main goal of studying heavy-flavour physics
- Tracks reconstructed down to p_T = 0 GeV/c with high vertex reconstruction resolution

New RICH1 optics, new PMTs and readout for RICH 1 & 2

removed M1 station + new readout

New luminometer (PLUME)



New VELO pixels

New SMOG2 system

New SciFi trackers (scintillating fibers)

Removed hardware level triggers + readout

Data processing

NEW **Readout at full 30 MHz rate**

NEW Full software trigger in two stages

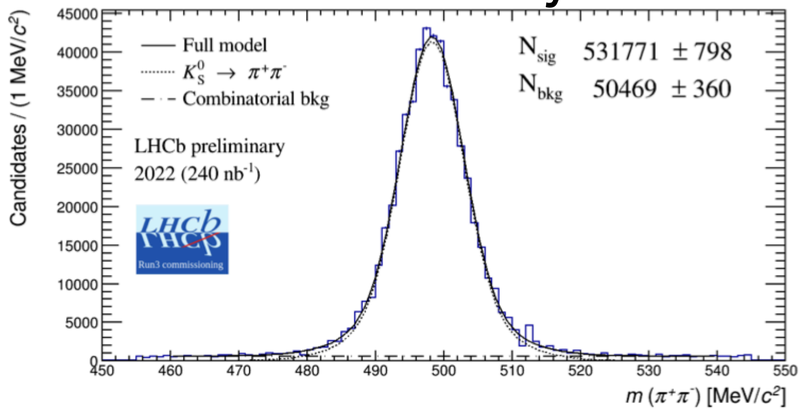
HLT1 (based on GPUs):

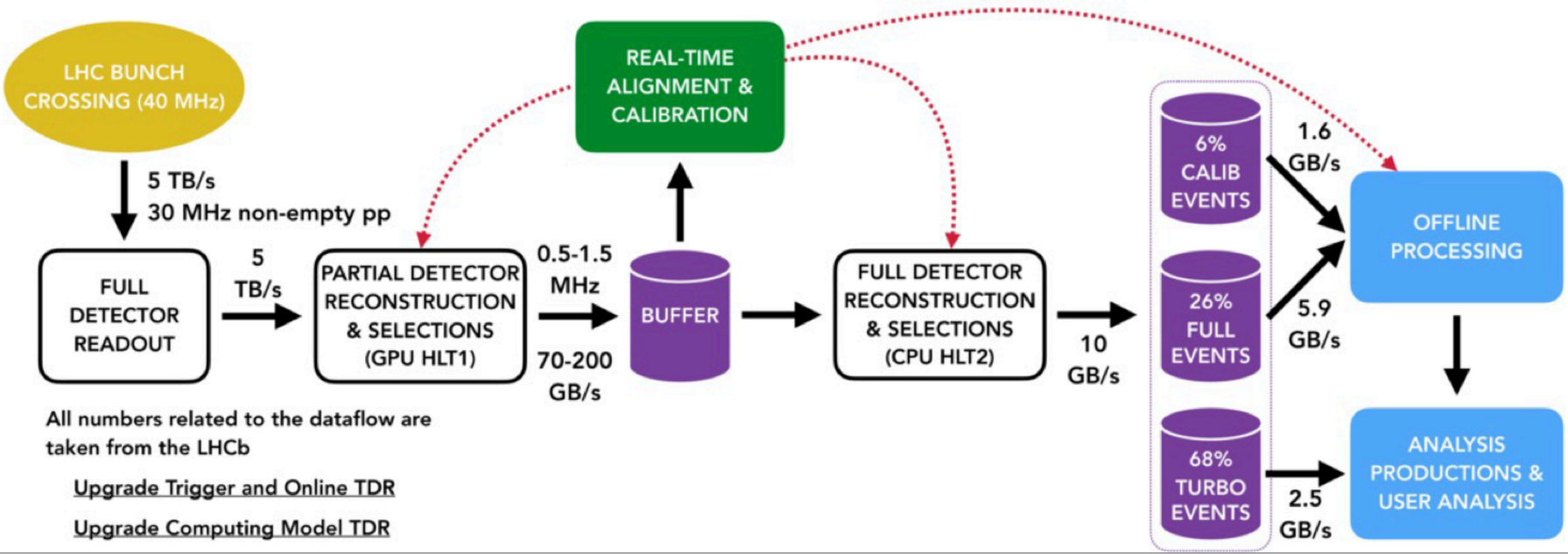
- Real time alignment & calibration
- Partial reconstruction (track + vertex + muon + simplified calo)
- Triggers for final states of different hadrons and displaced tracks

HLT2 (based on CPUs):

- Full reconstruction
- Physics selection lines

Reconstruction directly from HLT1





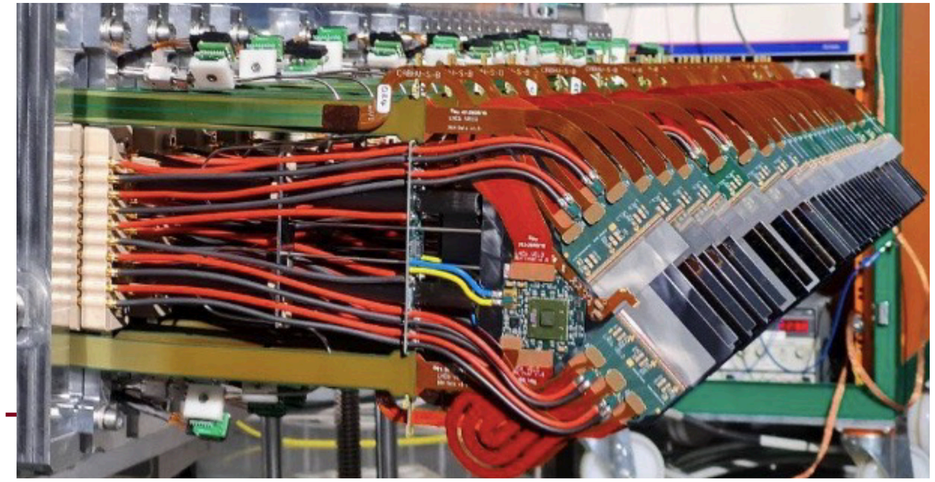
Different upgrades status

Vertex Locator:

Silicon pixel detector with increased granularity, acceptance and impact parameter resolution (no saturation in central Pb-Pb), allowing precise tracking and vertices

Design:

52 modules with a total of 41 M pixels
Pixel size of 55×55 μm² covering an area of approximately 1.2 m²
Two movable halves designed to get closer to the beam (3.5 mm)
Separation of primary (LHC beam) and secondary (VELO modules) vacuum by a 150 μm thick aluminium RF foil

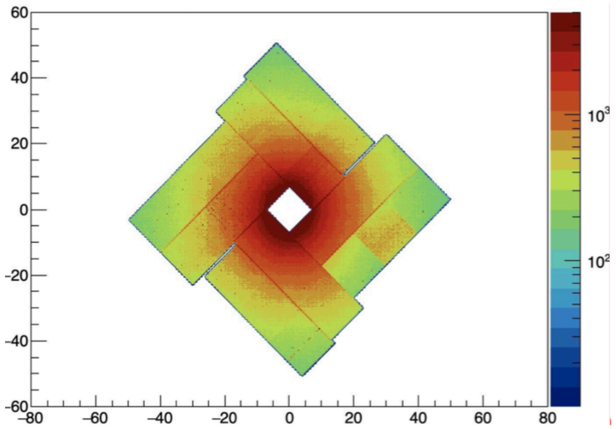


On January 10 2023, during VELO warm-up in Neon, there was a loss of control of protection system, deforming in the RF foils plastic up to 14 mm, affecting 2023 physics (VELO partially open)

RF foil replaced and ready to start 2024 with full power !

Operations:

- Data rate per ASIC pixel up to 15 Gb/s
- Higher than 99.6 % of links active
- Dedicated firmware to handle large events in PbPb
- Replacement of deformed boxes in January



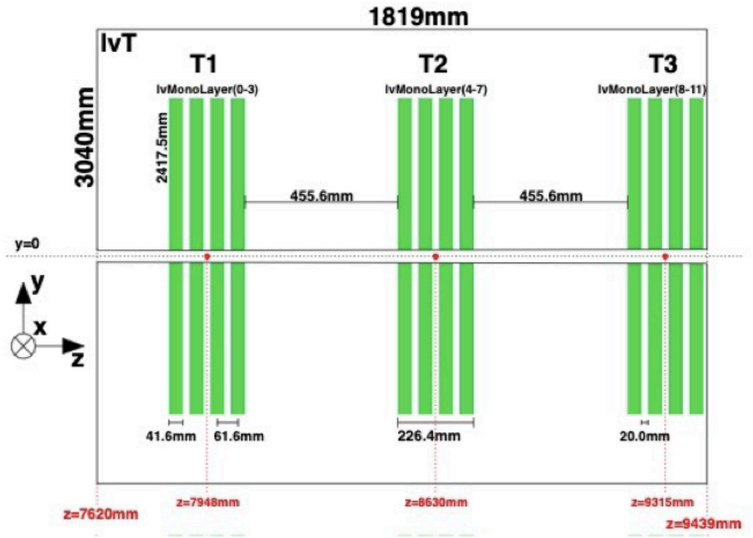
Different upgrades status

Scintillating Fibers tracker:

New tracking detector based on Scintillating Thin Fibers

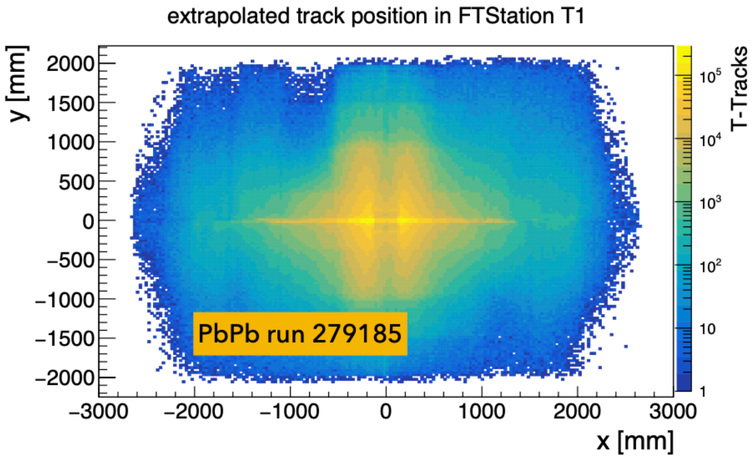
Design:

Scintillating fibres coupled to Silicon Photomultipliers operated at -40 °C
128 modules,12 planes (3 stations with 4 layers): 12000 km of fibres
Fibres (250 μm diameter) are 2.4 meters long
New ASIC with 64 channels using 130 nm CMOS technology



Operations:

- Stable during data-taking
- New firmware deployed for high occupancy regions allowing to record more clusters in PbPb



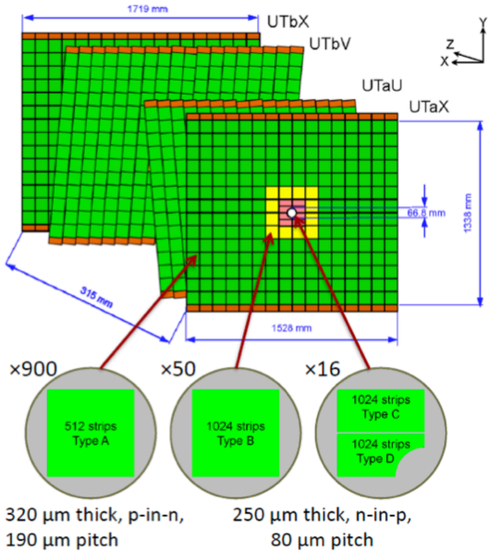
Different upgrades status

Upstream Tracker:

New tracker with high granularity silicon-microstrip sensors, crucial in reduction of ghost track rate

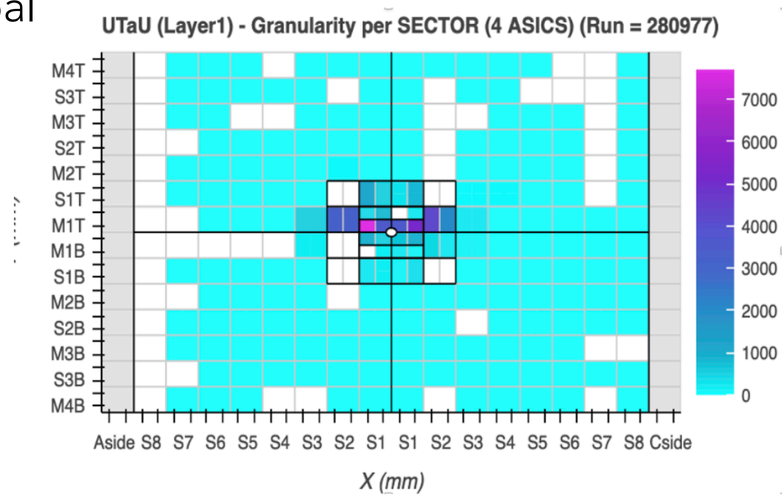
Design:

4 silicon micro-strip planes upstream of magnet
Increased granularity closer to the beam
Sensor pitch from 95 to 190 μm, with a thickness of 250 μm (kept at -5°C)
New readout ASIC, 128 channels with 6-bit ADC



Operations:

- First data collected in the global data-taking during Pb-Pb runs
- Uniform noise in the detector



Different upgrades status

Ring Imaging Cherenkov:

Identifies particles by measuring Cherenkov radiation angles, crucial for distinguishing between different types of charged hadrons.

Design:

RICH1 filled with C_4F_{10} and RICH2 with CF_4

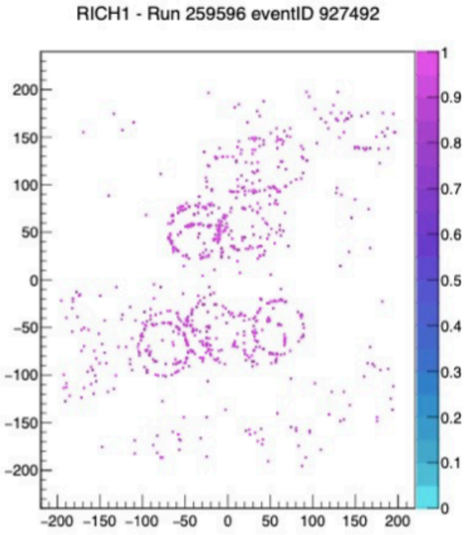
Replacement of Hybrid Photon Detectors with Multi-anode PMTs in both RICH1 and RICH2 (64 pixels covering 26.2 mm²)

Change curvature of RICH1 spherical mirrors to reduce occupancy on PMTs

New ASIC for readout (CLARO)

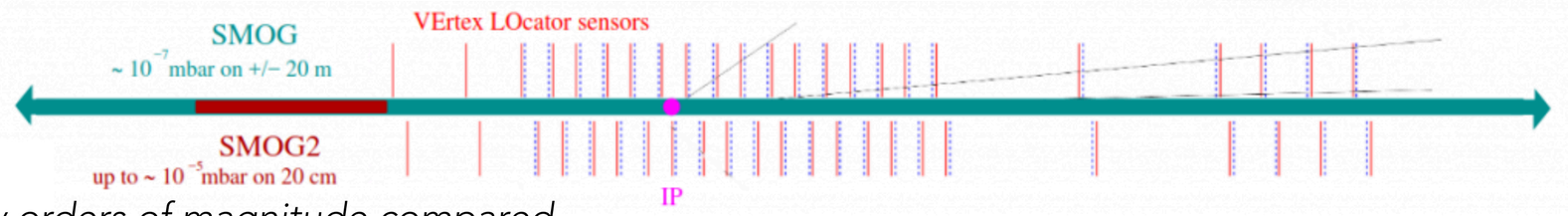
Operations:

- Cherenkov angle resolution better than in Run 2
- Efforts dedicated to calibrations and fine tuning
- Providing luminosity online (currents) and offline (hits)



Different upgrades status

SMOG2:



New gas injection system increasing interaction rate by orders of magnitude compared to previous SMOG

Storage cell

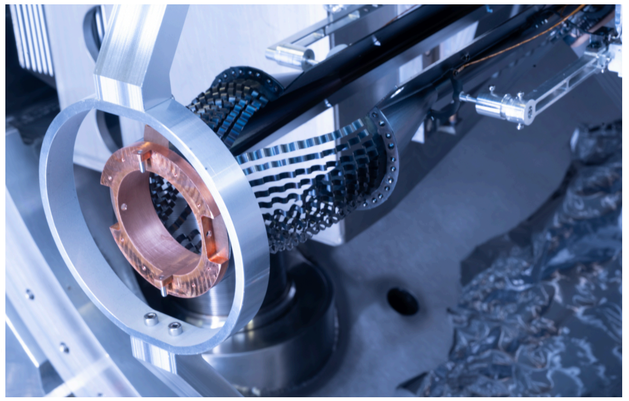
Capable of injecting various gases

Up to x100 **factor gain in luminosity**

All colliding bunches can be used

Possible simultaneous data-taking parallel to pp

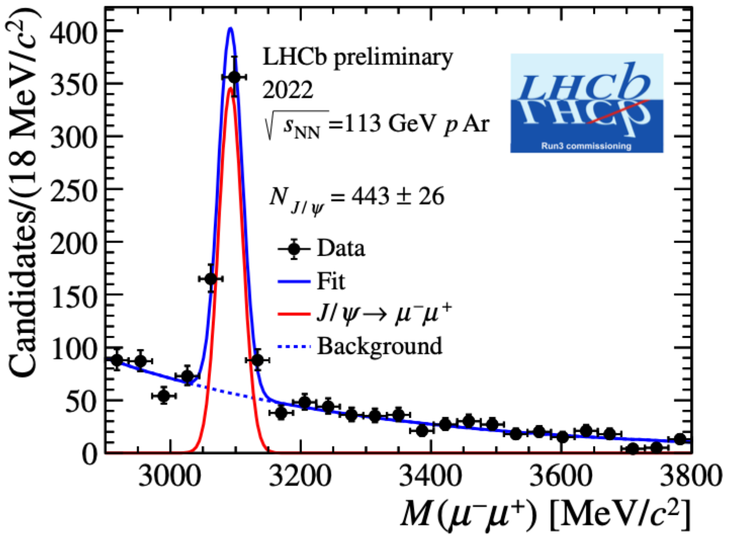
Precise luminosity determination with the control of gas density in storage cell



Operations:

- Cell not fully closed (attached to VELO) -> lower pressure
- Stable operations with injections
- Gas (Ar) injected with SMOG continuously during Pb-Pb

With only 18 minutes of Ar injection



First look at data

Very important commissioning year 2022 for LHCb:

2022

Several gas injection in SMOG2 was performed and participated in PbPb pilot run

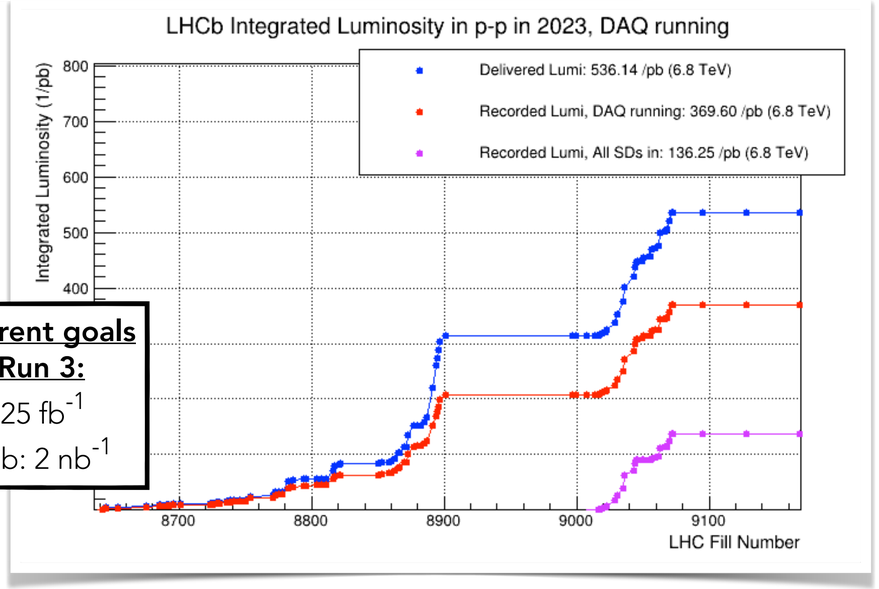
A lot of progress to understand detectors, alignment and calibration

VELO was open during all 2023 due to incident

2023

Detectors commissioning finishing and physics data recorded with good conditions

Around 136 pb^{-1} recorded luminosity with all SD included

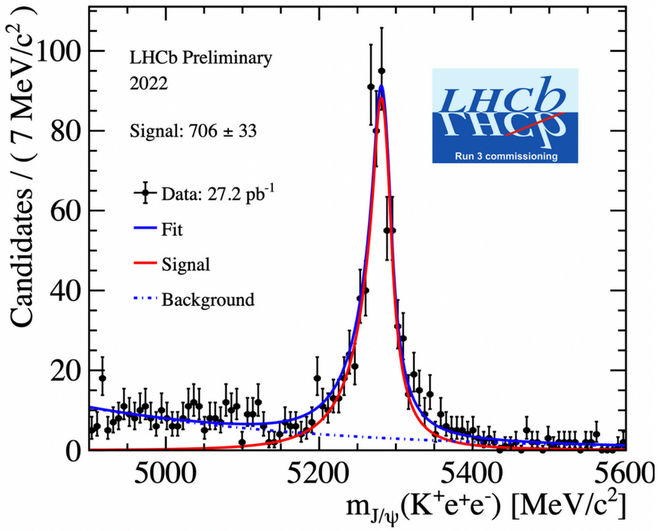


Current goals for Run 3:

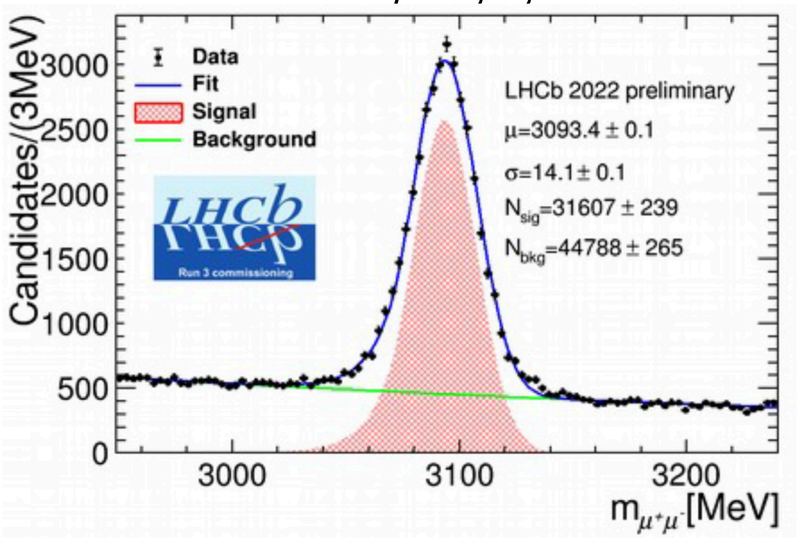
pp: 25 fb^{-1}

PbPb: 2 nb^{-1}

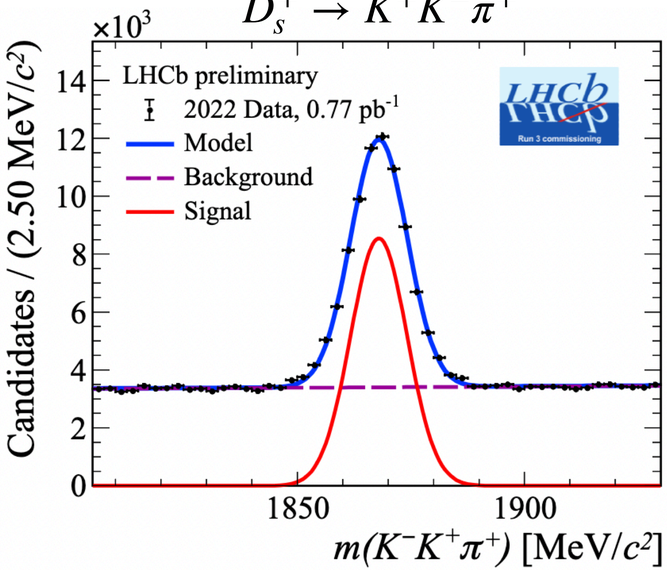
$B^+ \to J/\psi(e^+e^-)K^+$



$J/\psi \to \mu^+\mu^-$



$D_s^+ \to K^+K^-\pi^+$



What about Pb-Pb ?

Detectors status:

VELO operated with a 49 mm gap

Dedicated firmware deployed to efficiently manage large events

UT underwent commissioning, collecting first data in global

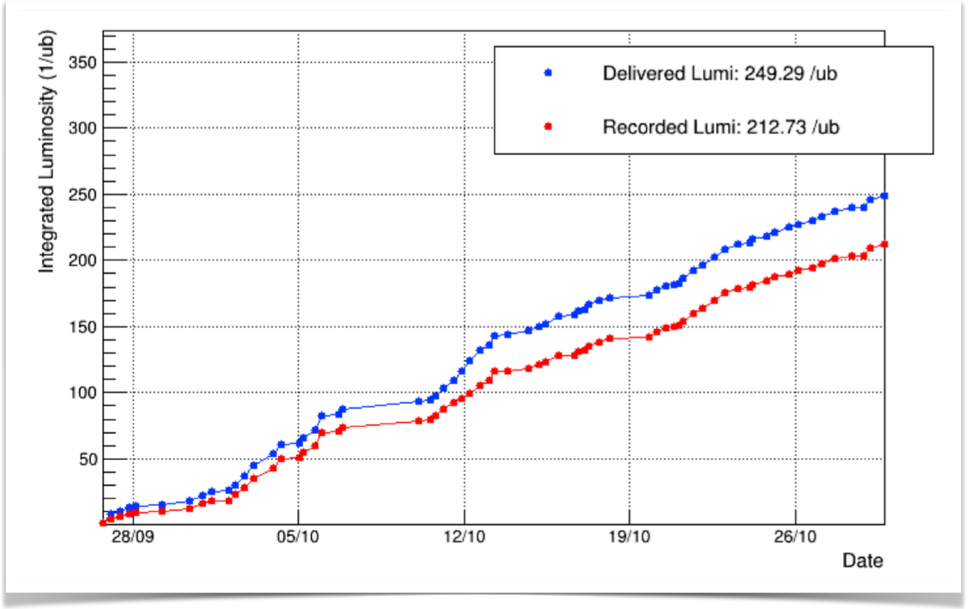
Continuous injection of Ar gas with SMOG2

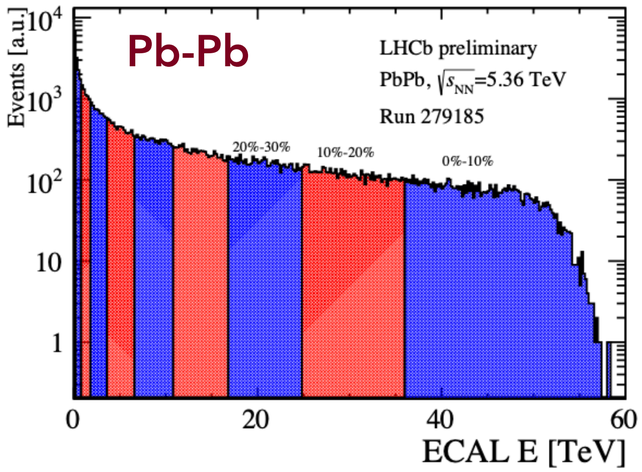
All other sub-detectors performed stably

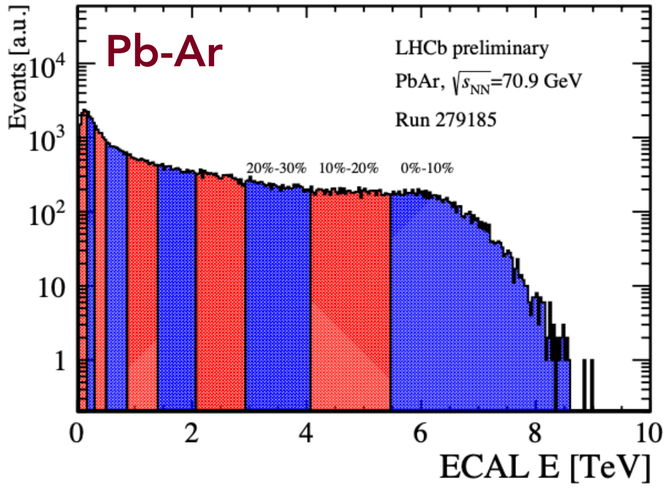
> Stable operations during ion runs

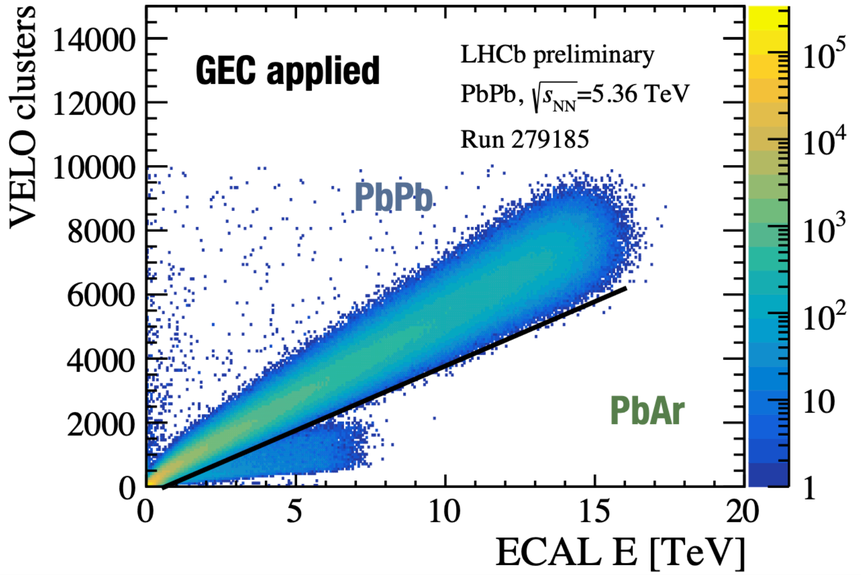
> Target centrality reached

> Reconstruction on-going





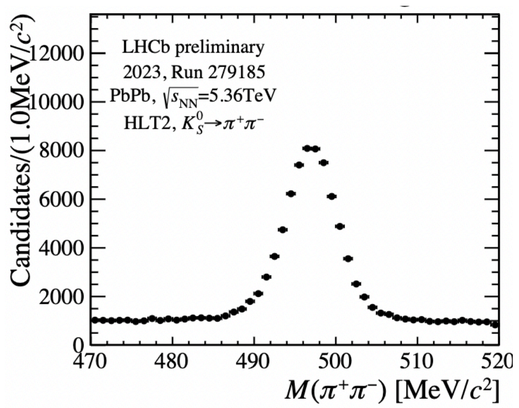


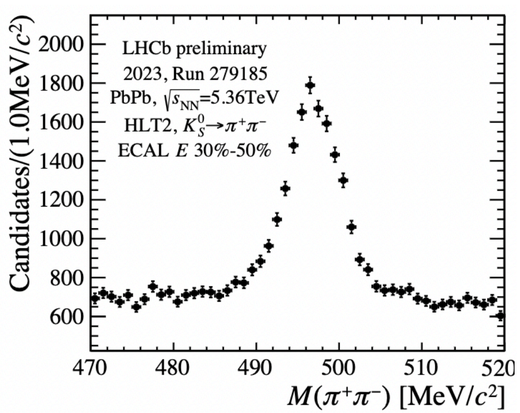


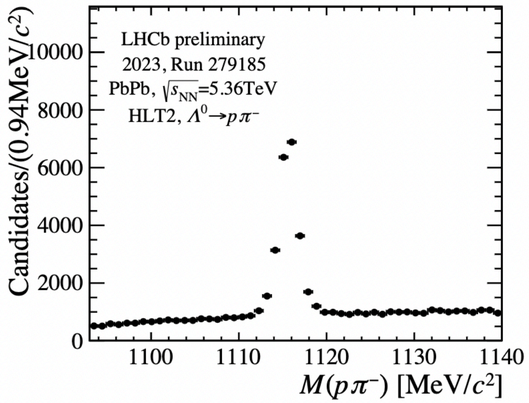
First Run 3 physics signal from Pb-Pb and Pb-Ar

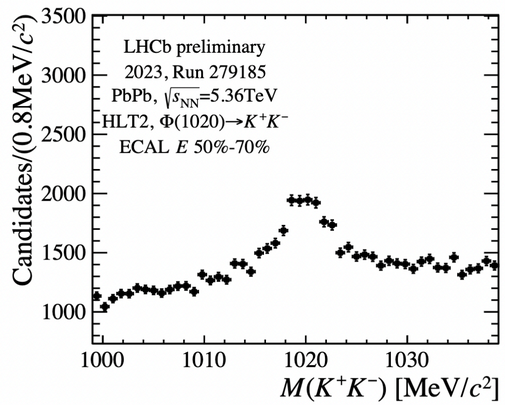
With only 40 minutes of data:

Pb-Pb data reconstructed down to 30% for the first time in LHCb:

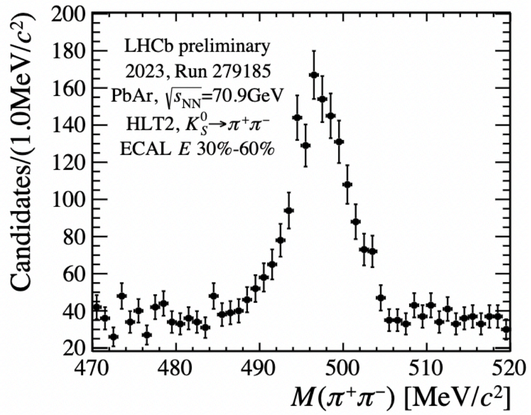


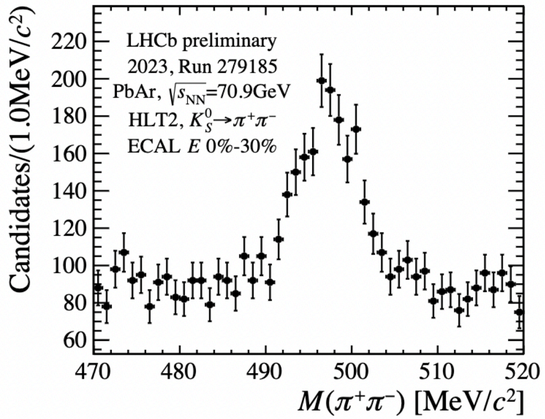


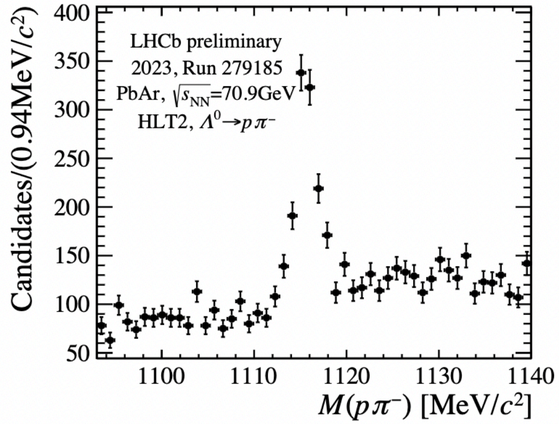




Pb-Ar data reconstructed down to full centrality for the first time in LHCb:







Promising access to QGP physics with this new centrality range !

Physics perspectives for Run 3

With the optimized tracking, bigger VELO acceptance, PID, new SMOG2, higher statistics, and the lower centrality reach, a wide axis of physics will be accessible for Run 3

The in between central and peripheral region holds particular intrigue, as it presents a challenge to current models which display discrepancies with the observed data

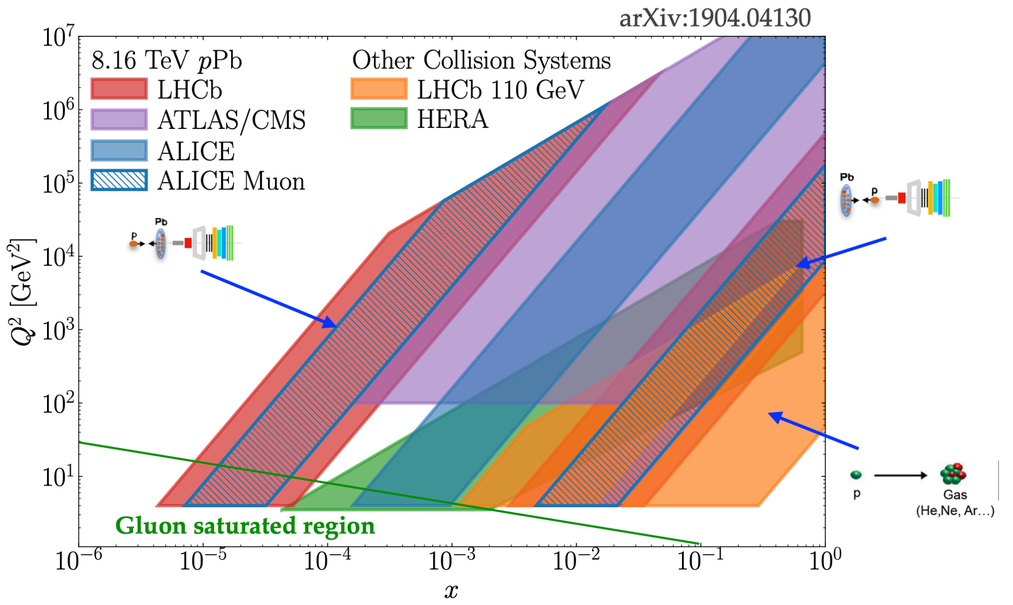
New measurement possible of the J/ψ, ψ(2s), χ_c and Y(nS) with new PbPb centrality reach down to 30 % and PbAr down to full centrality

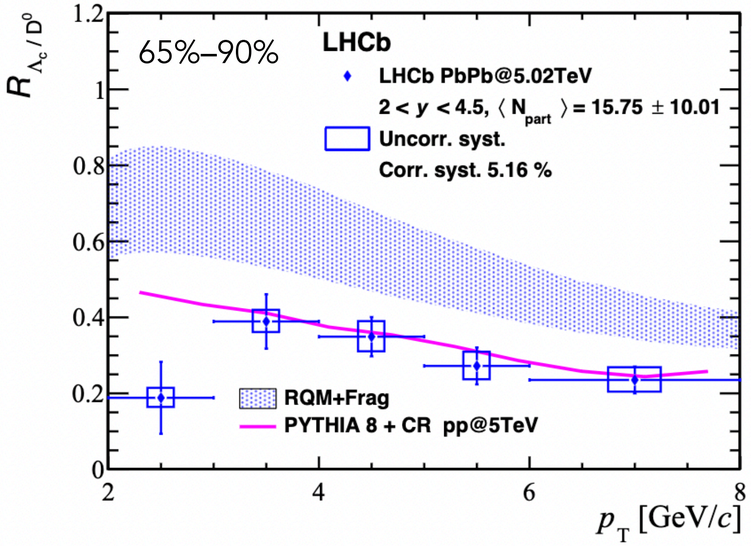
Quarkonia production in different and wide collision systems

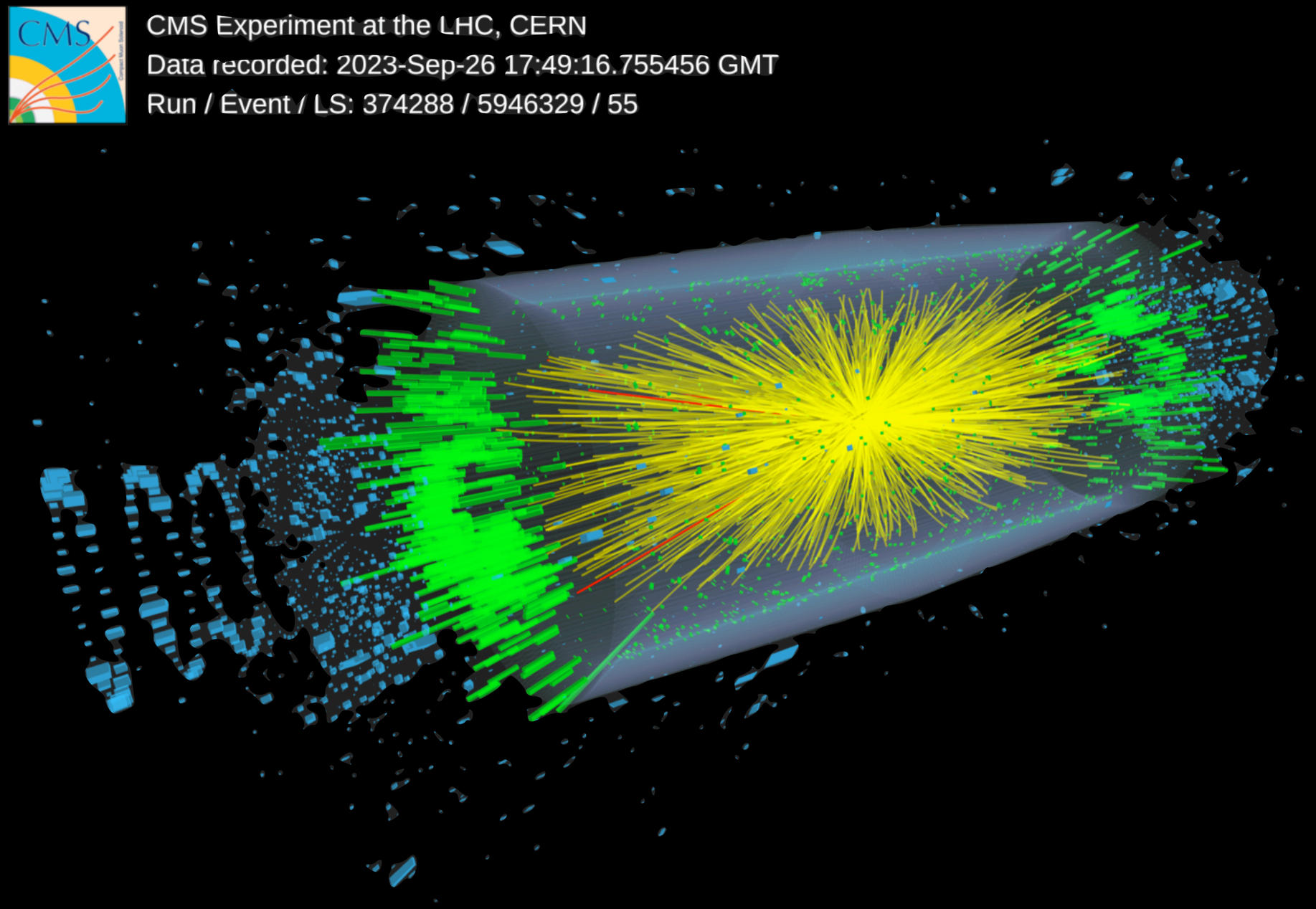
Investigation of hadronization mechanism with the Λc/D0 ratio in more central Pb-Pb collisions

Drell-Yan measurements

And many more!







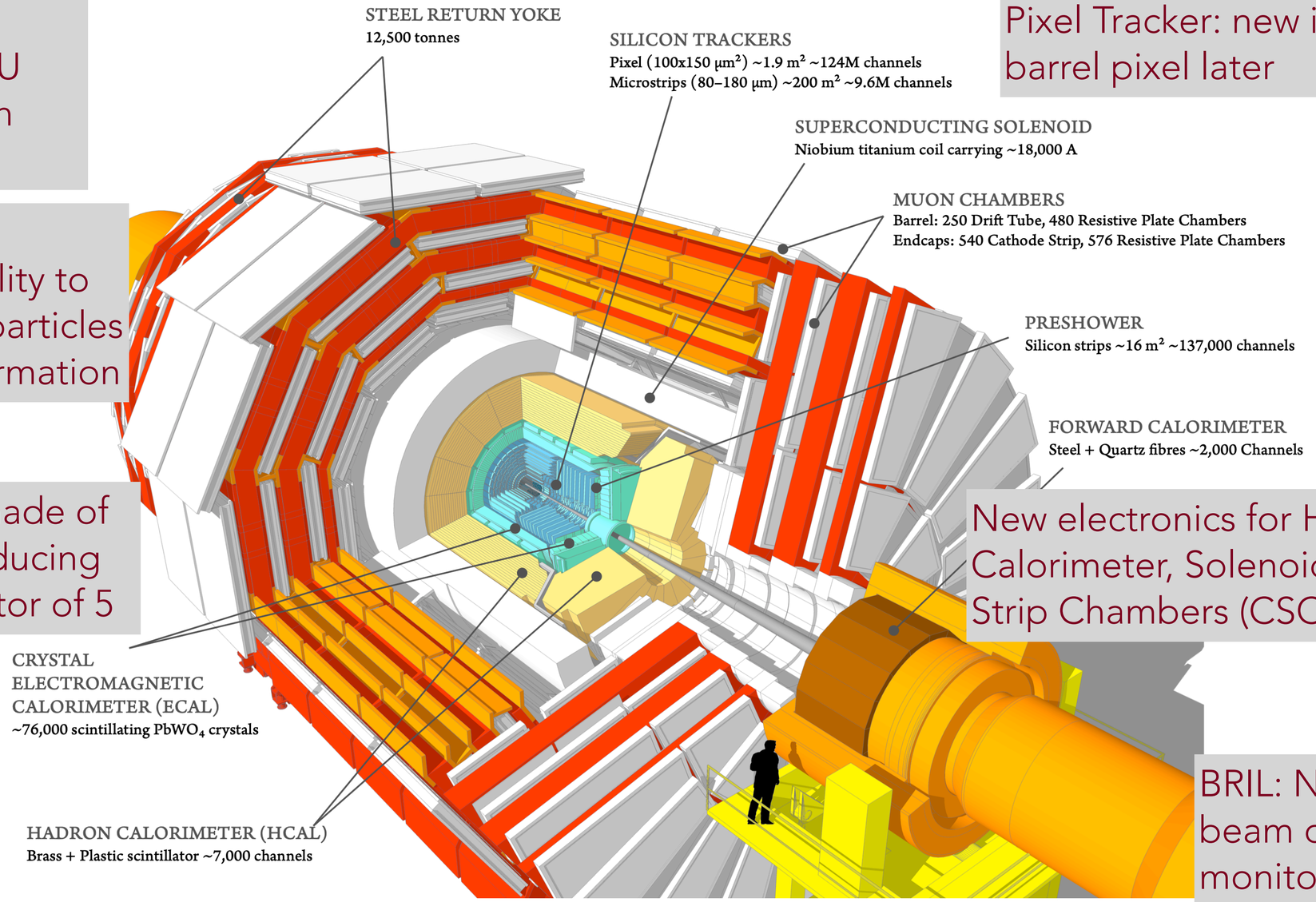
Run 3 overview:
CMS

CMS for Run 3

DAQ/HLT:
Transition to CPU+GPU
Significant reduction in processing time

L1 trigger:
Enhanced with capability to trigger on long-lived particles using calorimeter information

New beam pipe: made of aluminium alloy reducing radioactivity by factor of 5



Pixel Tracker: new innermost barrel pixel later

New electronics for Hadron Calorimeter, Solenoid Magnet, Cathode Strip Chambers (CSC) muon detectors

BRIL: New detectors for beam conditions monitoring and luminosity

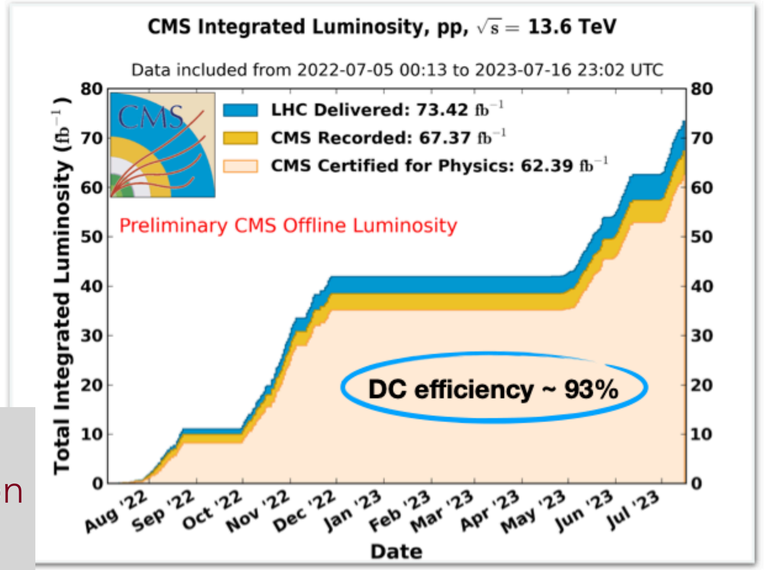
Operations status

2023

Around 5 weeks of PbPb data-taking at 5.36 TeV
Luminosity delivered by LHC: 1.98 nb-1 (1.8 nb-1 in 2018)
Luminosity recorded by CMS: 1.82 nb-1 (1.7 nb-1 in 1018)

Smooth operation of the CMS detector
Collected nearly all hadronic statistics, ~17 billion MB events
Collected around 10 billion UPC events

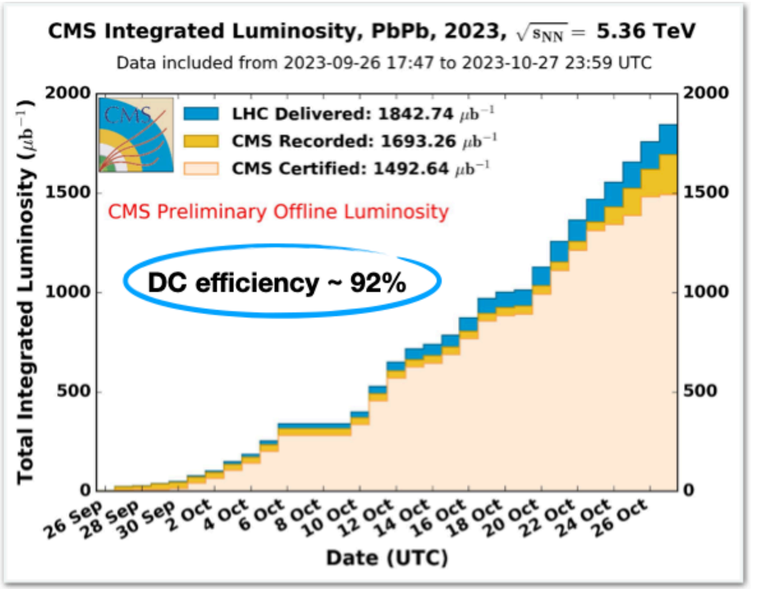
During HI data-taking:
New RAW format + HLT compression reduce data size by 54%



For the first time, CMS operated in PbPb collisions at a Level 1 trigger rate exceeding 50 kHz, from 35 kHz in 2018, with less than 8% deadtime.

Up to 50 kHz rate at the beginning of the fill during extensive MB data recording
Rates escalated beyond 60 kHz towards when collecting UPC events

Different physics triggers were employed to catch rare events (high pT jets, muons, ...)



Prospects for Run 3

Plan to analyze MB data instead of relying only on muon-triggered events, which are limited at low pT due to trigger inefficiencies

With the improved muon identification, the reconstruction of J/ψ down to pT = 0 GeV/c, even in the most central collisions

Investigation of J/ψ photoproduction in non-UPC events

Measurement of the Bc meson at lower pT than in 2018

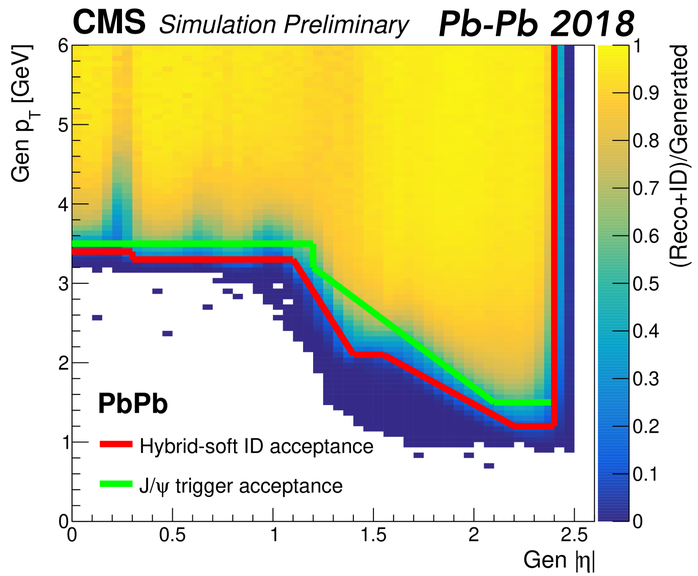
Measurement of X(3872) at lower pT

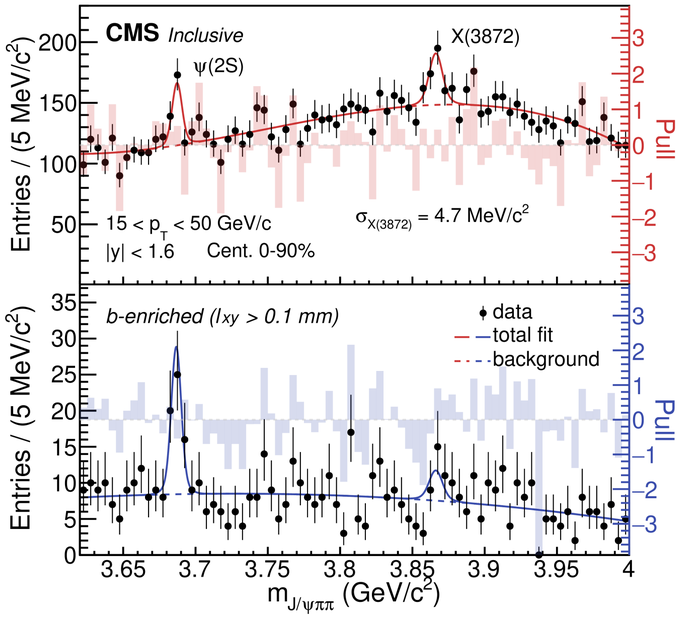
Ongoing and Planned Analyses:

Polarization studies of J/ψ at high pT and the Y(nS) states
Measurement of χ_c in peripheral collisions
Double J/ψ production

Long-term studies (to be done at the end of Run 3):

Elliptic flow and RAA of Y(nS) states
Examination of charmonium flows





Summary & conclusions

ALICE:

Recording & reconstructing data in continuous readout
Data taking at 500 kHz in pp & 50 kHz in Pb-Pb
First performance and physics signals arising for pp and Pb-Pb
Promising perspectives for quarkonia physics, new measurements possible and prompt & non-prompt separations to be expected at forward rapidities

LHCb:

Operating with readout at *30 MHz* rate
All the detectors finishing commissioning successfully
VELO is in place and ready for 2024!
Performance and physics signals for pp and Pb-Pb, with centrality extending down to expected 30 % and full centrality in PbAr
New measurements will be possible with heavy-ion collisions & fixed target

CMS:

Stable operations during Run 3
Measurements possible extending into the lower pT range

Thank you for your attention!